EORGIA INSTITUTE OF TECHNOLOGY

PROJECT ADMINISTRATION DATA SHEET

[x] ORIGINAL [ ] REVISION NO. ____

roject No. G-35-622 GTRI/~~GIT~~ DATE 2/18/83

roject Director: Dr. L. T. Long School/~~Lab~~ Geo Sci

ponsor: US Army Corps of Engineers, Savannah

ype Agreement: Contract DACW21-83-C-0014

ward Period: From 2/1/83 To 1/31/85 (Performance) 1/31/85 (Reports)

ponsor Amount: Total Estimated: $ 54,308 Funded: $ 54,308

ost Sharing Amount: $ ____ Cost Sharing No: ____

itle: Microearthquake Instrumentation and Analysis of the Richard B. Russell Dam and Lake Area

ADMINISTRATIVE DATA

OCA Contact Frank Huff

1) Sponsor Technical Contact:

~~Paul D. Robinson~~ M. F. REYNOLDS
Chief, Civil ~~Management Branch~~ WORKS PROGRAM
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Savannah, GA 31402

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Defense Priority Rating: None

Military Security Classification: None
(or) Company/Industrial Proprietary: ____

RESTRICTIONS

See Attached None Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval – Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with ____

COMMENTS:

Continuation of work done on G-35-687

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GEORGIA INSTITUTE OF TECHNOLOGY　　　　OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date April 26, 1985

Project No. G-35-622　　　　School/~~Lab~~ Geo Science

Includes Subproject No.(s) N/A

Project Director(s) D.T. Long　　　　GTRC / ~~GIT~~

Sponsor U.S. Corps of Engineers, Savannah, Georgia

Title "Microearthquake Instrumentation and Analysis of the Richard B. Russell Dam and Lake Area"

Effective Completion Date: 1/31/85 (Performance) 1/31/85 (Reports)

Grant/Contract Closeout Actions Remaining:　　　　Note: Fixed Price Contract

- [ ] None
- [x] Final Invoice or Final Fiscal Report
- [ ] Closing Documents
- [ ] Final Report of Inventions
- [x] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other ______

Continues Project No. G-35-687　　　　Continued by Project No. ______

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ANNUAL REPORT NO. 4
PROJECT NO. G-35-622

MICROEARTHQUAKE INSTRUMENTATION AND ANALYSIS BETWEEN HARTWELL AND CLARK HILL RESERVOIR AREAS

Annual Technical Report for Period 1 January 1983 - 31 December 1983

By

Dr. Leland Timothy Long
Professor of Geophysics
and
Russell Propes
Graduate Research Assistant

Prepared for

U. S. ARMY CORPS OF ENGINEERS
Savannah District
P.O. Box 889
Savannah, Georgia 31402

February 1984

GEORGIA INSTITUTE OF TECHNOLOGY
A Unit of the University System of Georgia
Engineering Experiment Station
Atlanta, Georgia 30332

1983

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School of Geophysical Sciences
Atlanta, Georgia 30332

MICROEARTHQUAKE INSTRUMENTATION AND ANALYSIS BETWEEN HARTWELL AND CLARK HILL RESERVOIR AREAS

INTRODUCTION

The Richard B. Russell Lake will cover the Savannah River valley in the Piedmont Province of Georgia and South Carolina from the headwaters of the Clark Hill Reservoir north to Hartwell Dam. Impoundment of the Savannah River was initiated in December 1983. While most reservoirs do not trigger microearthquakes when they are first impounded, there is evidence that some reservoirs in the Piedmont Province of South Carolina and Georgia have induced seismic activity. The objective of the microearthquake instrumentation and the analysis of data on events occurring between the Hartwell and Clark Hill Reservoirs Areas is to document the seismicity prior to, during, and after impoundment of the Richard B. Russell Lake. This report covers the maintenance of the seismic monitoring system from 1 January 1983 to 31 December 1983.

SEISMICITY

The earthquakes observed in the Piedmont Province (Figure 1) occur at scattered locations with little apparent correlation with major geologic structures. Where reliable estimates of their depth are available, the implied depths are shallow and are typically less than two kilometers deep. The largest, the Union County earthquake of 1913, was, perhaps, a magnitude 5.5. The rate of activity is low, with an average of one event greater than magnitude 3.5 occurring less than once every four years in South Carolina and Georgia. Today, the seismicity at magnitudes less than 2.0 is difficult to assess because the shallow focus earthquakes typical of the Piedmont Province generate signatures similar to the signatures of industrial explosions in the many quarries which mine the near-surface crystalline rocks. The seismic monitoring system will detect earthquakes or blasts less than magnitude zero. Hence, an initial objective of the analysis of seismic monitoring data between Hartwell and Clark Hill Reservoir Areas is to identify the active quarries and other industrial blast sites in order to properly assess the background level of seismicity.

The area of the Richard B. Russell Lake does not exhibit any historical seismicity, although the area has experienced disturbances from more distant events, such as the 1886 Charleston earthquake and the Clark Hill vicinity earthquakes. The two closest epicenters based on currently available data are near Due West and McCormick, South Carolina. Due West is approximately 40 km east of the Savannah River and experienced earthquakes in 1929, 1930, 1931, and 1956. The earthquake near McCormick occurred August 2, 1974. On November 1, 1875, a maximum intensity VI (mm) earthquake was noted in the Clark Hill

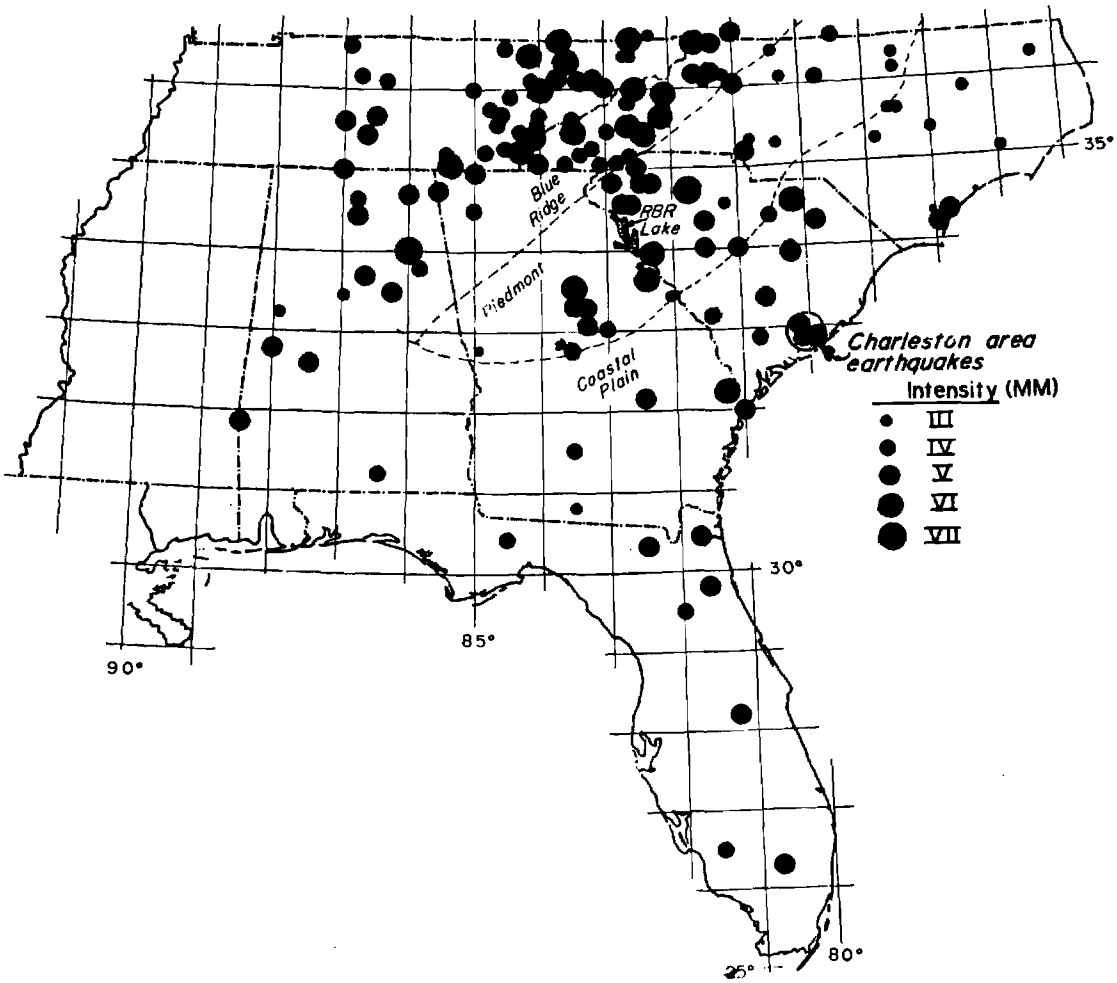


Figure 1. Seismicity of the southeastern United States and its relation to the proposed Richard B. Russell (RBR) Lake.

Reservoir Area near Lincolnton, Georgia. These two events occurred 10 to 20 km south of the Richard B. Russell Dam site.

Many of the recent earthquakes in the Piedmont Province have epicenters near reservoirs. These include the Seneca earthquake on July 13, 1971; the Jocassee earthquakes of 1975, 1976, and 1979; and the August 2, 1974, McCormick earthquake. Monticello Reservoir north of Columbia, South Carolina, triggered an extensive sequence of small (magnitude 2.5 to 3.0) earthquakes. Lake Sinclair, Georgia, has exhibited a continuous sequence of events, although the reservoir was impounded in the '50's and the association with the reservoir is tenuous. Lake Oconee, impounded in the spring of 1979, generated only a short sequence of small (less than M = 0) events in the spring of 1980. The Oconee reservoir events would not have been noted without a sensitive seismic net. Hence, one can speculate that other reservoirs similarly triggered events, but these events were undetected. In the case of Monticello and Oconee, seismic monitoring was available prior to loading and no significant seismic activity was detected in the vicinity of the forthcoming reservoirs. While at present the pre-impoundment seismicity does not allow predictions of induced earthquakes, it can provide valuable data concerning the occurrence of natural seismic activity.

The Richard B. Russell Lake will cover a 130 sq-km area of the Piedmont Province, an area in which nearby reservoirs are associated with induced seismic activity. Hence, the probability is high that Richard B. Russell Lake may induce some seismic activity. If seismic activity is induced near the Richard B. Russell Lake, the earthquakes will most likely be small, generally unfelt, and less than magnitude 2.5. Earthquakes with magnitudes as large as 3.5 are not common near Piedmont Province reservoirs (only two events with magnitudes greater than 3.2 occurred at Jocassee) and magnitudes larger than 4.5 are highly unlikely. Earthquakes could conceivably be induced anywhere near the reservoir. An objective of the seismic monitoring is to locate sites of activity should they develop after impounding the reservoir. Because their depths are expected to be shallow, perhaps as shallow as 0.5 to 1.5 km, the widely spaced net cannot determine accurate depths of focus. Instead, portable equipment would be deployed with appropriate spacing to compute depths of focus for events in selected active areas.

SEISMIC NET

The Richard B. Russell seismic net consists of three vertical-component short-period seismic systems. The three stations (see Figure 2) form a triangle elongated in the north-south direction. A fourth station, CHF, is scheduled to be added to the net in January 1984. The three sites are furnished and maintained by the Savannah District Corps of Engineers. Maintenance of the microearthquake monitoring system is provided through the mutual support of Georgia Tech and the Savannah District Corps of Engineers. Georgia Tech and the Savannah District

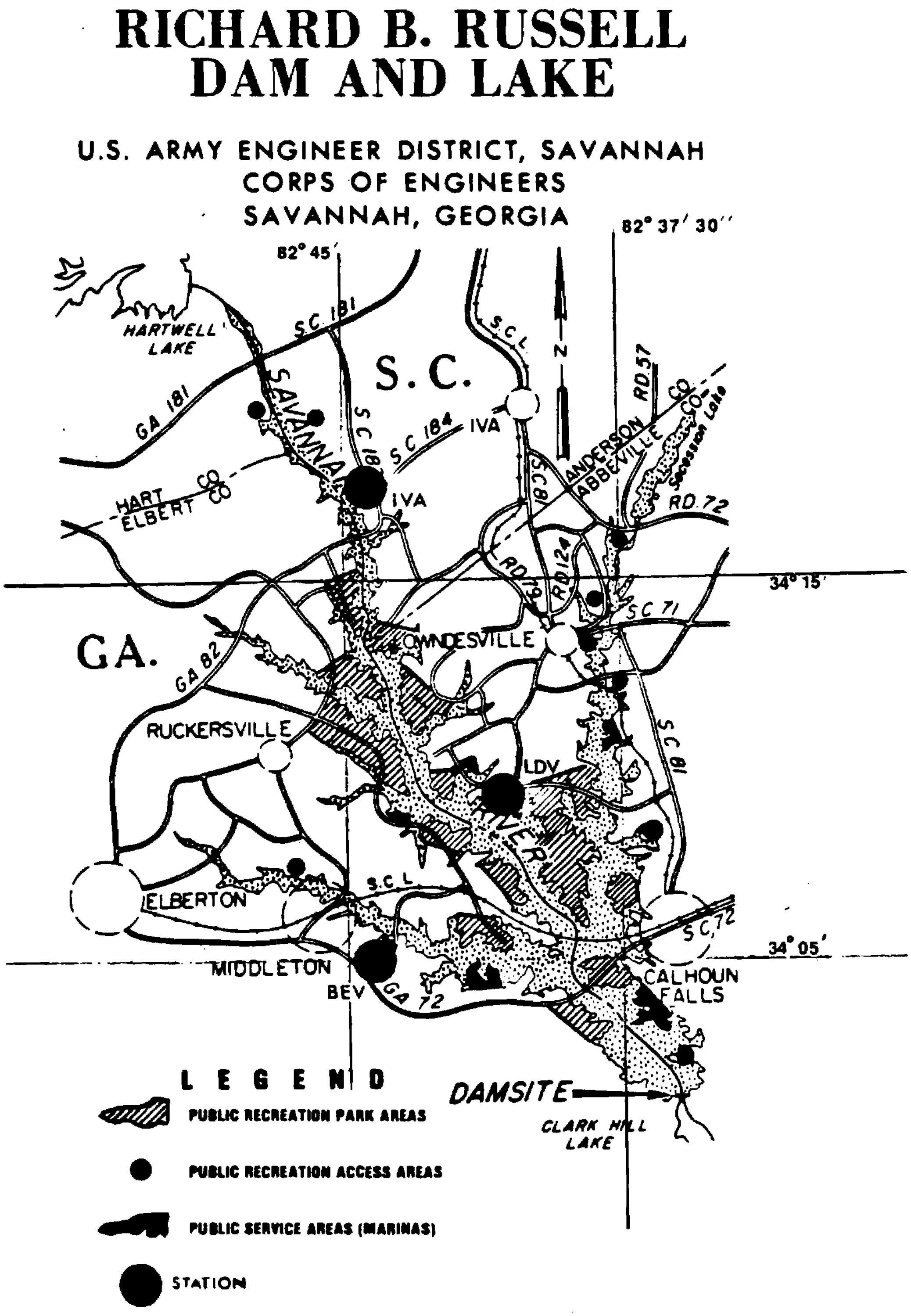


Figure 2. Location map for the three-station Richard B. Russell Lake Seismic Net.

Corps of Engineers also agree to the mutual use of the microearthquake monitoring system in the area between Hartwell and Clark Hill Reservoirs. Use of the data is confined to non-profit research. Requests for the usage of the data can be submitted directly to Georgia Tech. However, Georgia Tech must forward all requests to the Savannah District Corps of Engineers for approval. A brief report describing the data usage, the seismic events, and copies of the appropriate events shall be submitted to the Savannah District Corps of Engineers.

The designation for the northernmost station is IVA because it is 8 km west-southwest of Iva, South Carolina. IVA is within 1.0 km of the Savannah River and 13 km southeast of Hartwell Lake. Station LDV is 8 km south-southwest of Lowndesville, South Carolina, and 15 km northwest of the Richard B. Russell Dam site, at the headwaters of Clark Hill Reservoir. Station BEV is near the former town of Beverly, Georgia, and 14 km west-northwest of the dam site. Detailed descriptions of the locations of the three stations IVA, LDV, and BEV are given in Appendix I.

The regional distribution of seismic stations is shown in Figure 3. Station CHF is about 1.0 km east of the Richard B. Russell Dam site. Station CHF was originally funded by the Savannah District Corps of Engineers and eventually installed by the U.S. Geological Survey. The station originally consisted of one vertical and one horizontal short-period seismometer. The data were telemetered to Columbia, South Carolina, where they were recorded on a helical recorder. Station CHF did not operate during 1983. Station PRM on Parsons Mountain is part of the South Carolina Seismic Net operated by the U.S. Geological Survey. Stations EP1, CH5, and CH6 in the Clark Hill area are operated by Georgia Tech with the support of the Nuclear Regulatory Commission. At Georgia Tech, the Clark Hill stations are combined with the three Richard B. Russell stations to form a 75 km linear array. Additional seismic coverage to the north is provided by station SMT operated by Duke Power and the University of South Carolina. To the south, the Savannah River Plant operates a three-station array. To the southeast, station MTT, operated by the U.S. Geological Survey, is part of the South Carolina Net.

INSTRUMENTATION

The components of the microearthquake monitoring system were provided by the Savannah District Corps of Engineers. The system was assembled and installed by Georgia Tech. The specifications and construction of the system were made uniform in order to provide uniform response characteristics.

A vault was constructed to house the instruments in the field (see Figure 4). The vault was designed to provide a 10 to 20 cm thick cement base on which to rest the geophone. Sites were chosen to allow placement of the cement pad as close to bedrock as possible, and on a

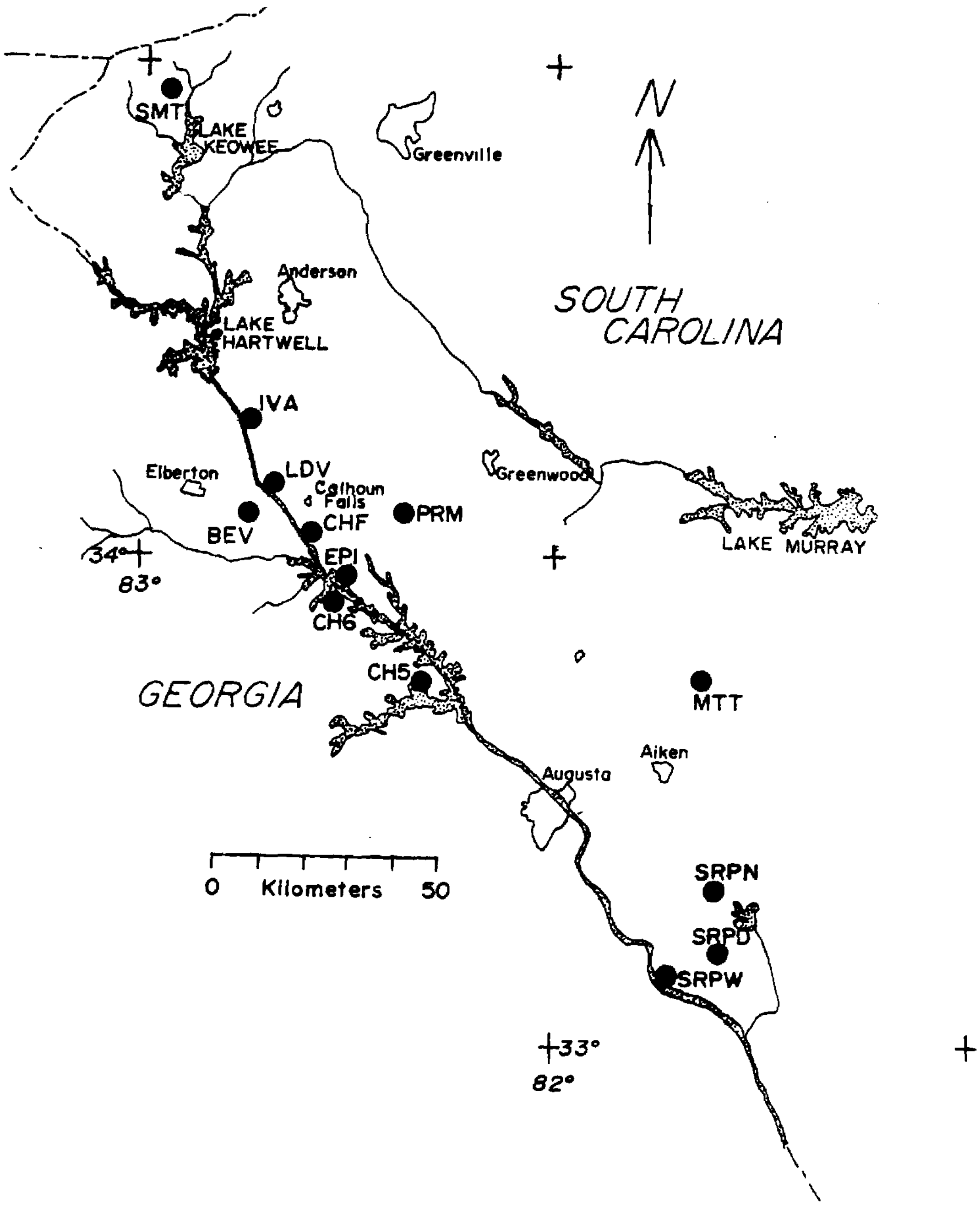
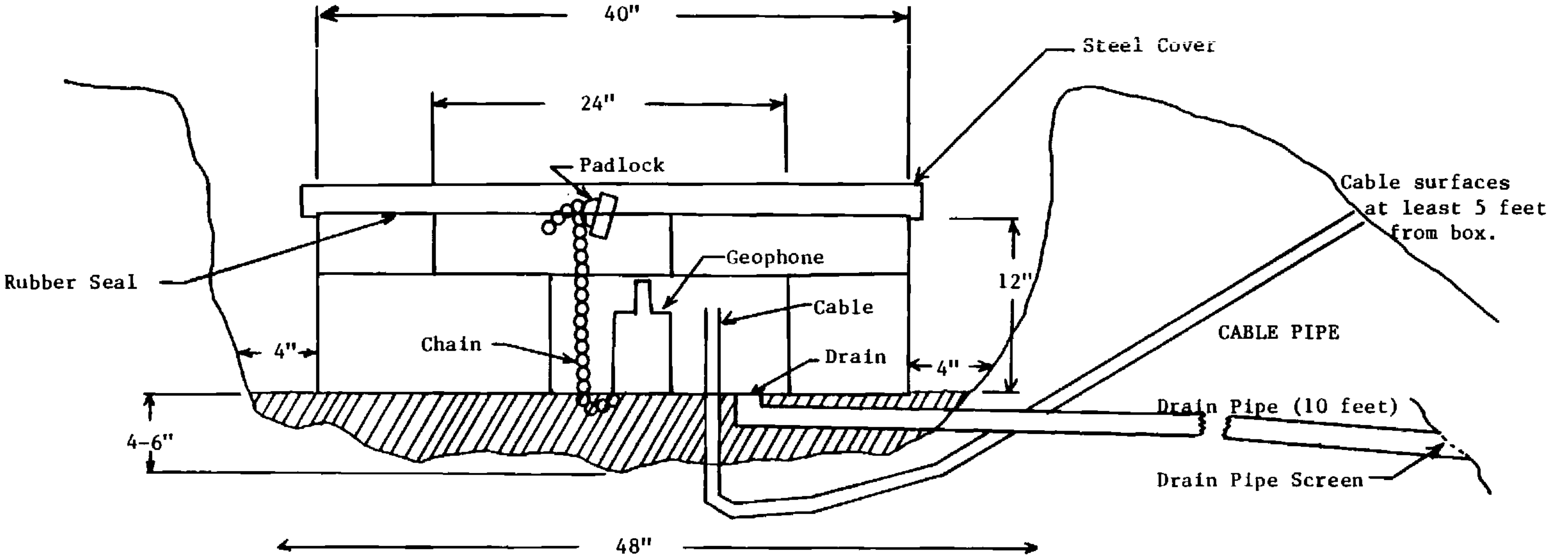
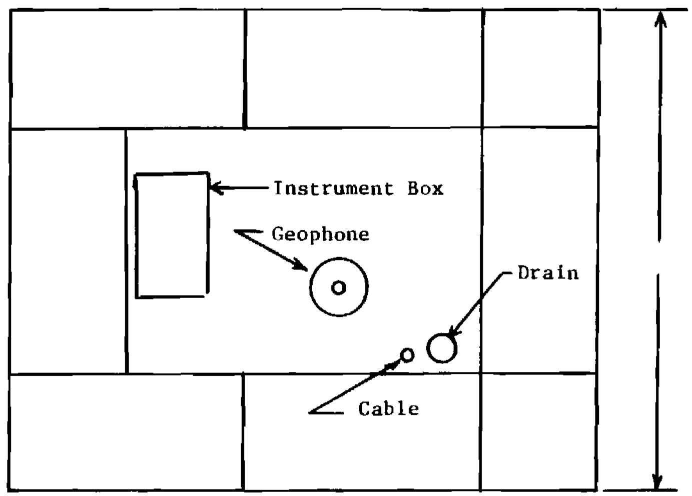


Figure 3. Location of seismic stations along the Savannah River.





Notes

1. Steel cover dimensions -- 33" x 41" x 2"
2. Drain -- 2" plastic hose; length 6 ft. to 12 ft.
3. Cable pipe -- 2" diameter; length 8 ft. to 12 ft.
4. Dimensions of hole -- 48" x 42" at bottom; 24" deep
5. Rubber seal is for vibration isolation and is not airtight.
6. Base is contoured to drain off or away from geophone pad and instrument box. Instrument box is installed about ½" above concrete.

Figure 4. Specifications for the seismic vaults built for the Richard B. Russell Seismic Net.

sufficient slope to guarantee drainage. Cinder blocks were used to build the walls and the top was covered by a welded iron cover. The design provides for both drainage of water and circulation of air. The instruments are housed in separate weather-proof containers for their protection.

Figure 5 shows the lightning protection circuitry that has been designed and implemented into the system in an attempt to reduce instrument damage due to lightning strikes. Figure 6 shows the assembly of the field instrumentation, and Figure 7 shows the instrumentation used in the monitoring system at Georgia Tech. The frequency modulated signal is transmitted to Georgia Tech via commercial telephone lines. In 1983 radio frequency transmission to the radio tower at the Richard B. Russell Dam was installed in order to minimize phone line costs amd lightening damage related to the connection of the equipment to the phone line. At Georgia Tech, the telephone line signal is conditioned for proper impedance matching for the discriminators. The discriminator bank is designed for plug-in expansion from the existing 3 to 7 possible stations. A patch cord system is used to route the discriminated signals to helical recorders. The timing system for the network is provided by means of a digital timing system at Georgia Tech and provides second, minute, hour, and twenty-four hour marks for the ink recorders.

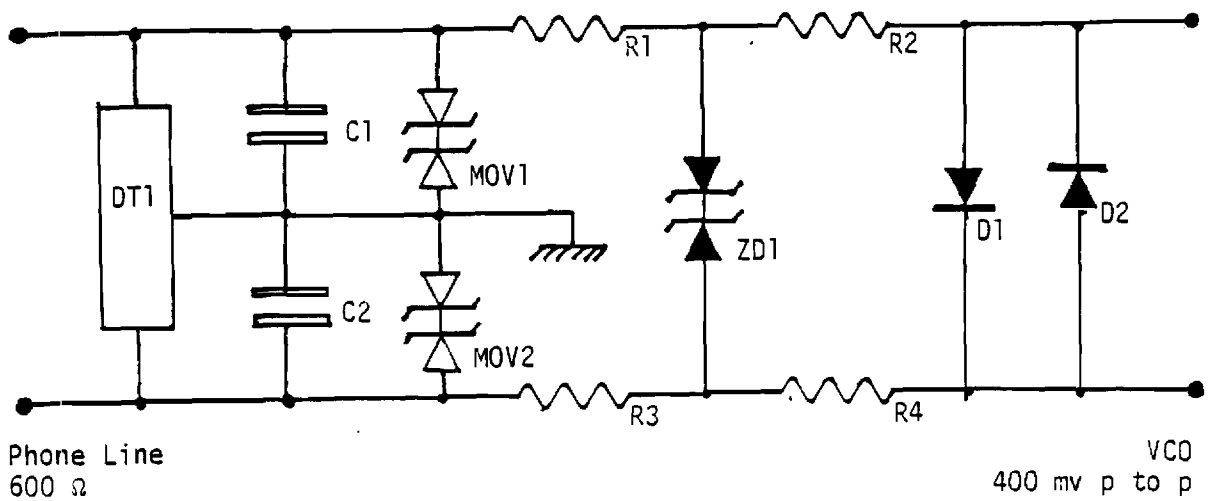
DATA ANALYSIS

The objective of the data analysis is to review all records obtained from the microearthquake recording system and compute locations and magnitudes for earthquakes recorded by the system. Seismic activity occurring within the immediate vicinity of the reservoir, as defined by a 50 km radius from the Savannah River, will be reported to the Savannah District Corps of Engineers. Discrimination of earthquakes from local quarry blasts or construction explosions requires, in addition, that the principal active quarries be located and identified. In order to simplify the task of identifying quarry blasts and construction explosions, a catalog of common blasts as recorded at each station has been developed (Figures 8A - K). Through the use of this chart, a higher percentage of previously located blasts can be identified without requiring the careful measurement of phases for a computer location. This means also that a seismic event is less likely to be mistaken for a blast. Figure 9 identifies the area of investigation and the currently identified sites of explosions.

The data analysis presented in this report covers the time period from 1 January 1983 to 31 December 1983. The average percent coverage over the twelve month period was 92% for at least one station, 72% for two stations, and 15% for three stations. Table 1 gives a detailed monthly breakdown of coverage.

During the course of the year, several regional seismic events were detected by the stations IVA, BEV, and LDV. This is a good indication

Audio Protection



Parts List

DT1, DT2 -- Discharge Tube, Tii 80-04P, 317A, 150-300 VDC
C1, C2, C3, C4 -- 0.005 μf, 1 kv
R1, R3 -- 50 Ω 10w
R2, R4 -- 10 Ω 10w
R5, R6 -- 1 Ω 10w
ZD1, ZD2 -- GS1-SKE20C
MOV1 - MOV4 -- V130LA20B
D1, D2 -- General Purpose Switching Diode IN 414A, etc.
D3 -- IN4002

Power Protection

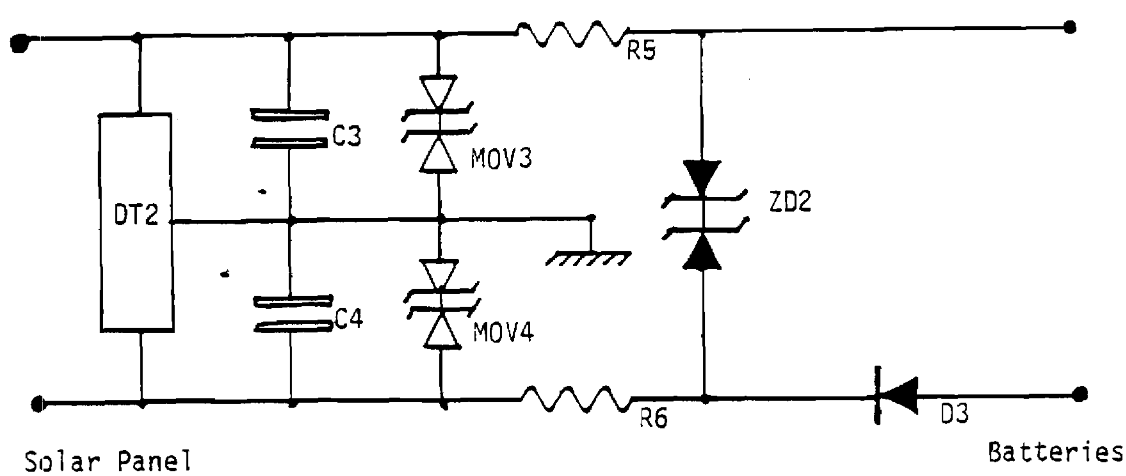


Figure 5. Lightning protection circuitry.

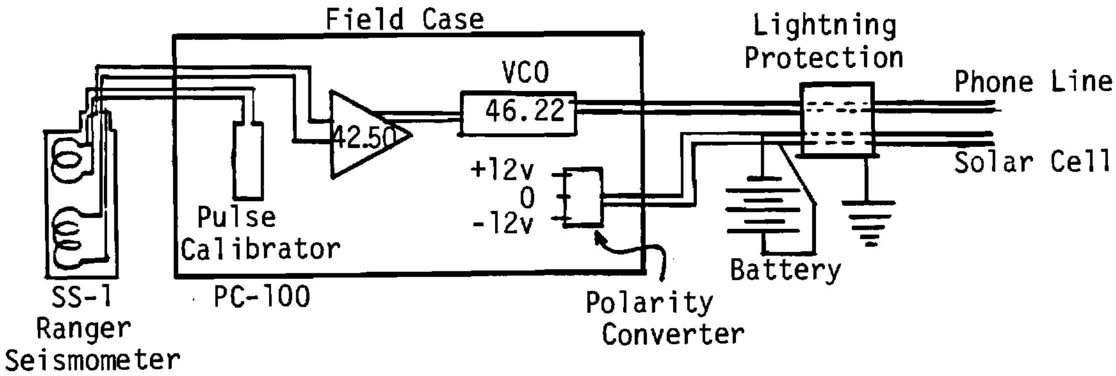


Figure 6.

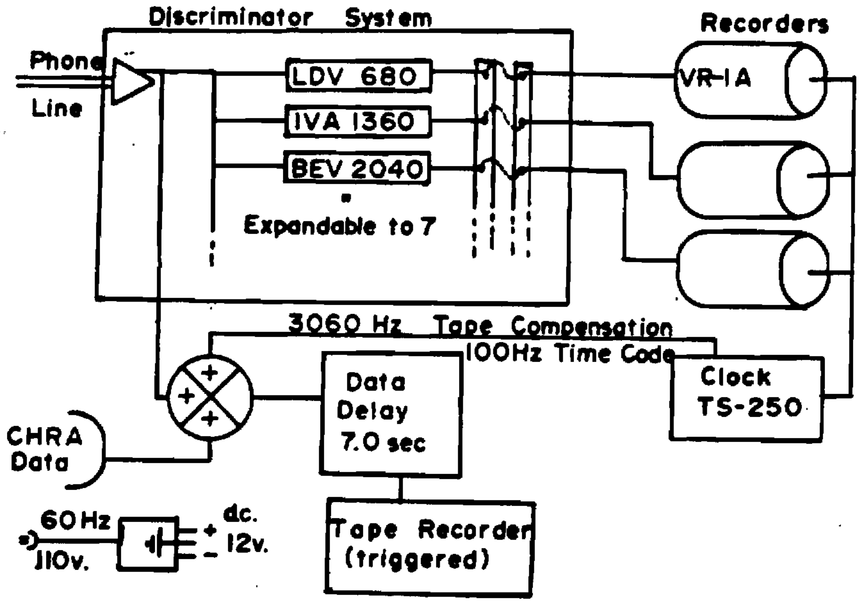


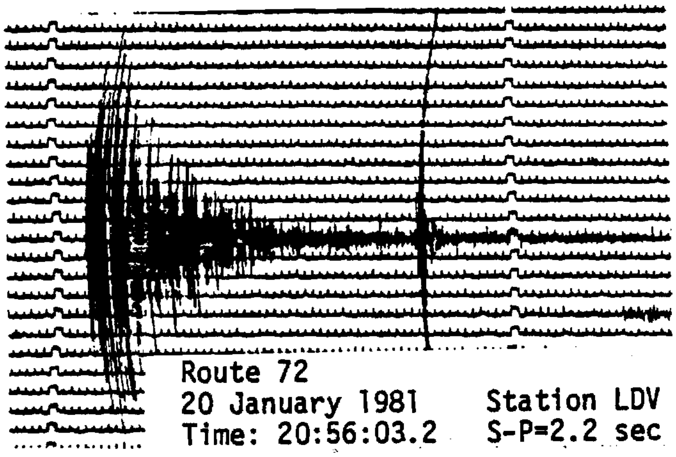
Figure 7.

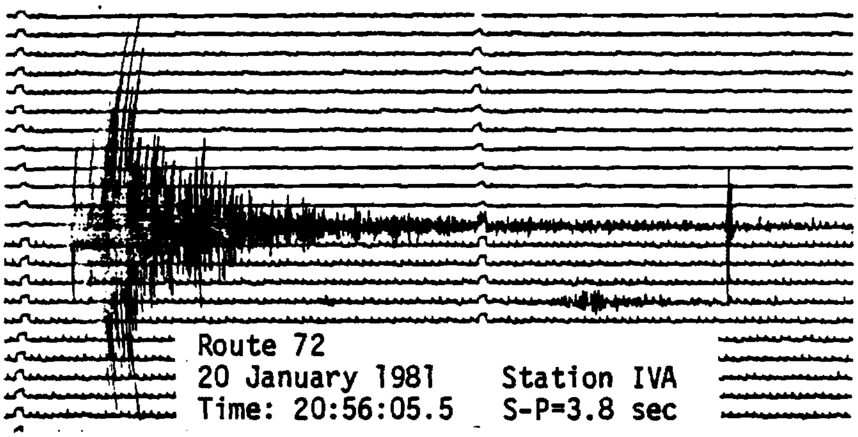
Figure 6. Field instrumentation design for the Richard B. Russell Lake Seismic Net.

Figure 7. Design of the Richard B. Russell Lake Seismic Net instrumentation at Georgia Tech.

that the above stations are indeed picking up seismic events of a nature other than blasts, and that they are functioning properly. A catalog indicating the character and specifics of the regional events can be found on pages 24-34.

No natural seismic events have been detected in the defined area of the Richard B. Russell seismic net.


Route 72
20 January 1981
Time: 20:56:03.2
Station LDV
S-P=2.2 sec


Route 72
20 January 1981
Time: 20:56:05.5
Station IVA
S-P=3.8 sec

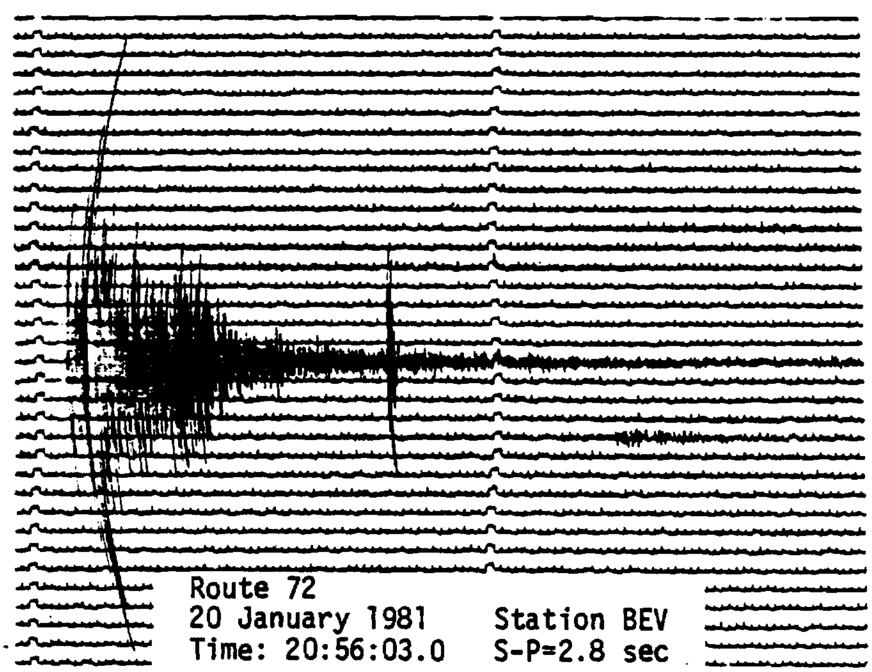

Route 72
20 January 1981
Time: 20:56:03.0
Station BEV
S-P=2.8 sec

Figure 8A.

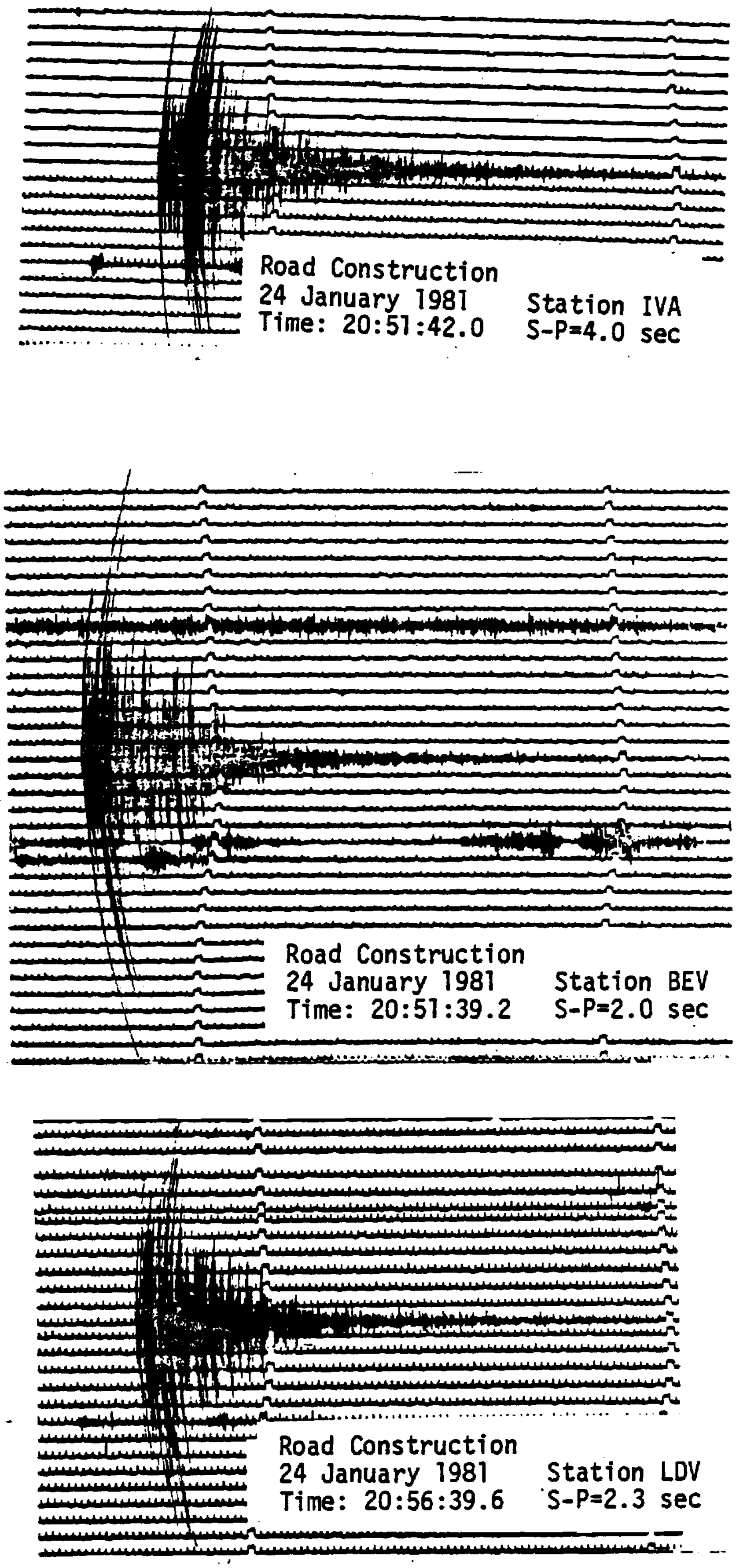
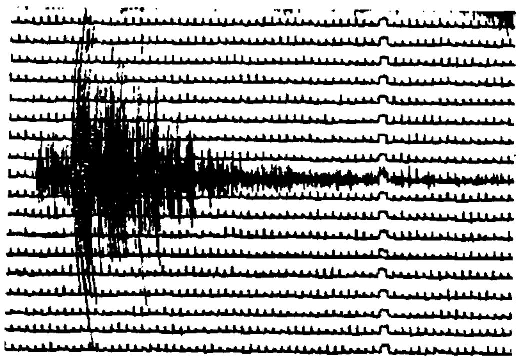
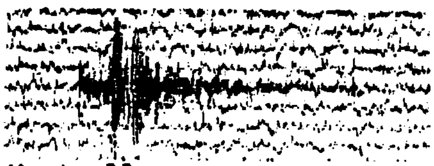

Road Construction
24 January 1981
Time: 20:51:42.0
Station IVA
S-P=4.0 sec
Road Construction
24 January 1981
Time: 20:51:39.2
Station BEV
S-P=2.0 sec
Road Construction
24 January 1981
Time: 20:56:39.6
Station LDV
S-P=2.3 sec

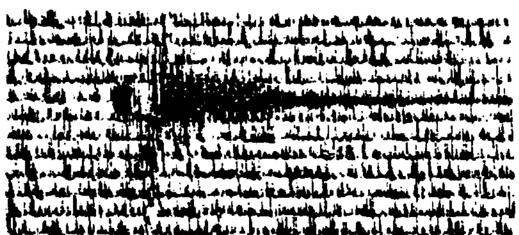
Figure 8B.



Hartwell Quarry, GA
01 June 1983 Station BEV
Time: 19:05:15 S-P=4.8

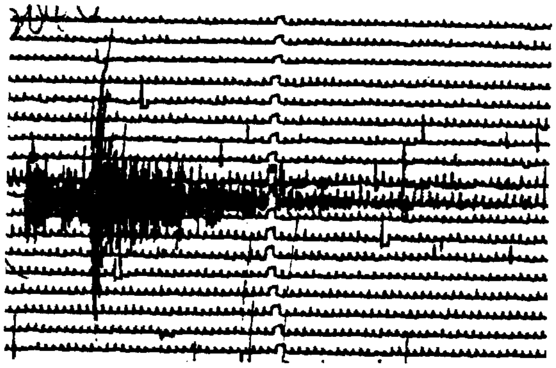


Hartwell
17 July 1981 Station LDV
Time: 16:15:56 S-P=4.0 sec

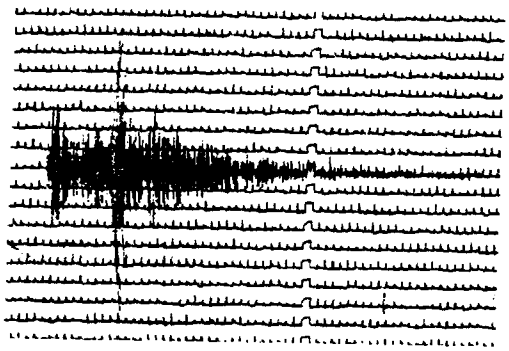


Hartwell
17 July 1981 Station IVA
Time: 16:15:54 S-P=3.2 sec

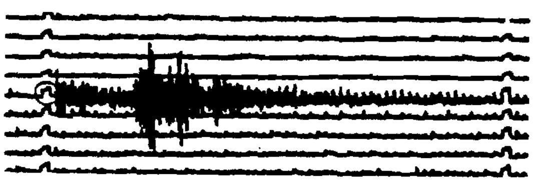
Figure 8C.



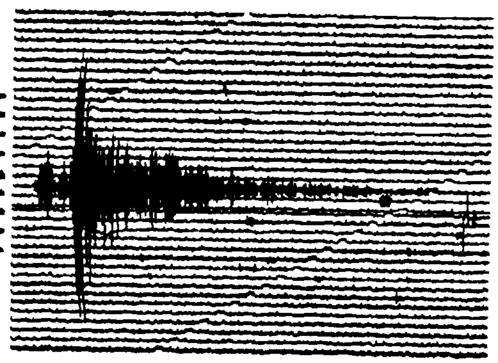
Thomson Quarry, GA
12 July 1983 Station LDV
Time: 20:46:28 S-P=9.2



Thomson Quarry, GA
13 June 1983 Station BEV
Time: 18:13:26 S-P=8.5

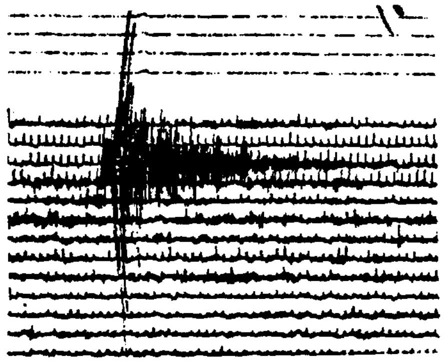


Thomson Quarry, GA
12 October 1983 Station IVA
Time: 17:28:02 S-P=10.5



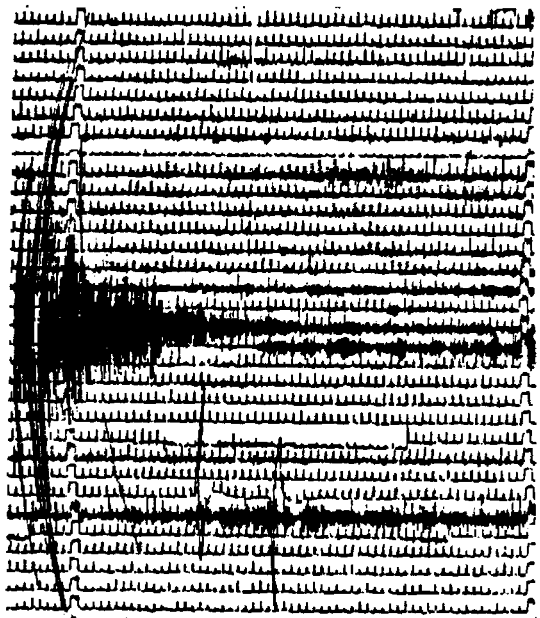
Thomson Quarry
17 March 1983 Station CH5
Time: 20:41:08 S-P=5.0

Figure 8D



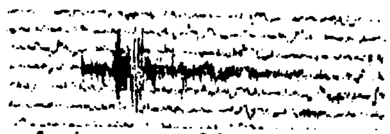
Richard B. Russell Dam
14 August 1981 Station LDV
Time: 18:58:13.5 S-P=1.4 sec

Figure 8E.

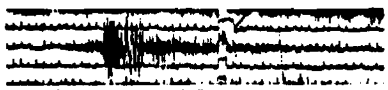


Calhoun Falls, SC
28 August 1981 Station CH6
Time: 18:58:12.5 S-P=2.0 sec

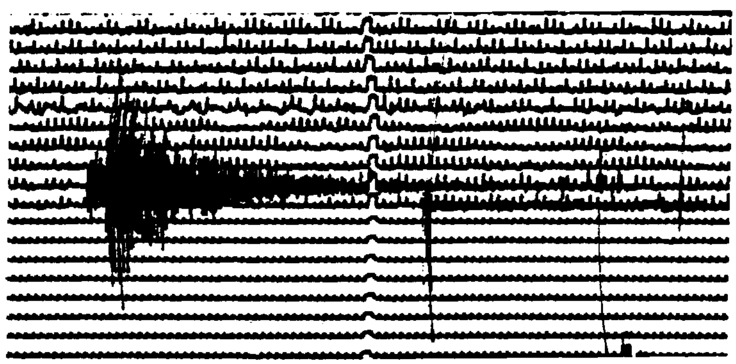
Figure 8F.



Anderson, SC
6 October 1981 Station LDV
Time: 16:14:39 S-P=4.0 sec

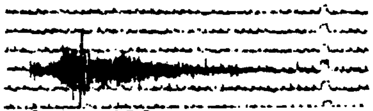


Anderson, SC
6 October 1981 Station BEV
Time: 16:14:40 S-P=4.8 sec

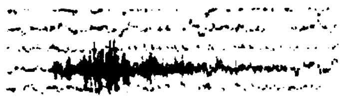


Anderson Quarry, SC
17 October 1983 Station IVA
Time: 20:48:23 S-P=3.0

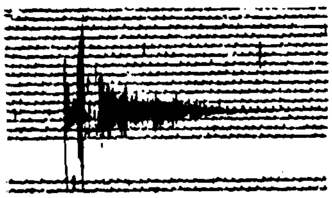
Figure 8G.



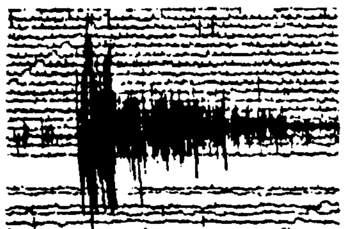
Abbeville Quarry, SC
9 October 1981 Station BEV
Time: 15:48:22 S-P=6.0 sec



Abbeville Quarry, SC
9 October 1981 Station LDV
Time: 15:48:23 S-P=5.0 sec

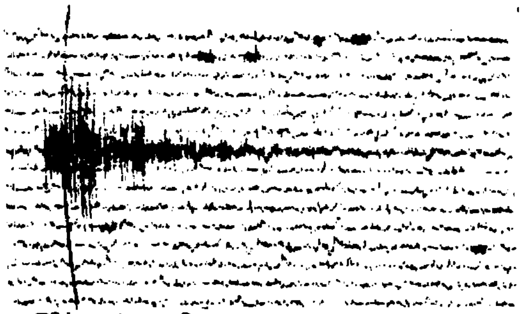


Abbeville Quarry, SC
9 October 1981 Station EP1
Time: 15:48:18.5 S-P=2.0 sec

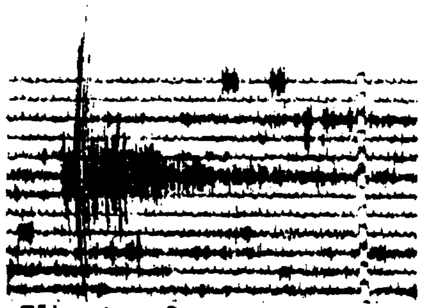


Abbeville Quarry, SC
9 October 1981 Station CH6
Time: 15:48:19.2 S-P=1.8 sec

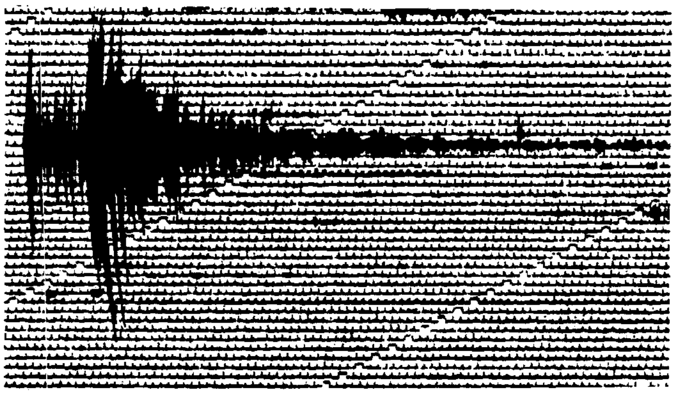
Figure 8H



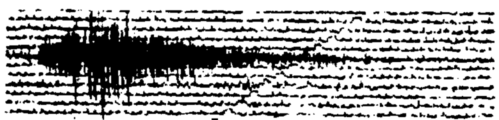
Elberton Quarry
9 October 1981 Station LDV
Time: 17:30:22 S-P=2.4 sec



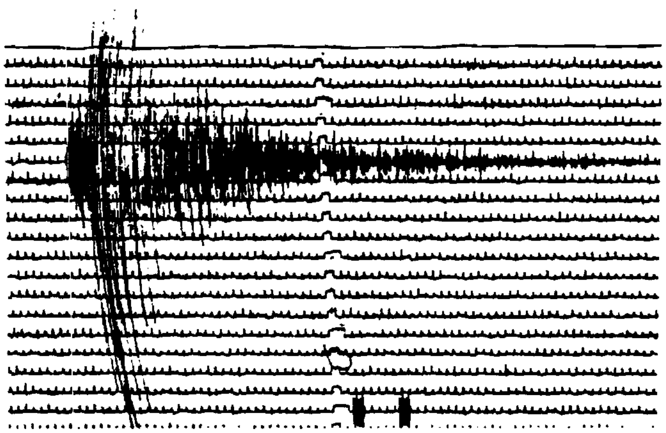
Elberton Quarry
9 October 1981 Station BEV
Time: 17:30:21 S-P=1.7 sec



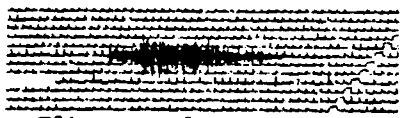
Elberton Quarry, GA
04 April 1983 Station CH5
Time: 20:03:25 S-P=8.2



Elberton Quarry
9 October 1981 Station CH6
Time: 17:30:25 S-P=6.0 sec

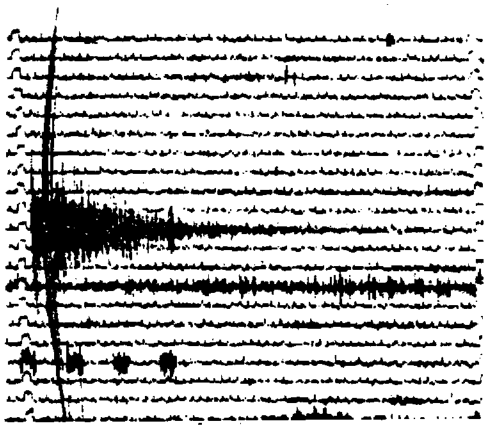


Elberton Quarry, GA
19 Feb. 1983 Station IVA
Time: 17:44:27 S-P=2,9

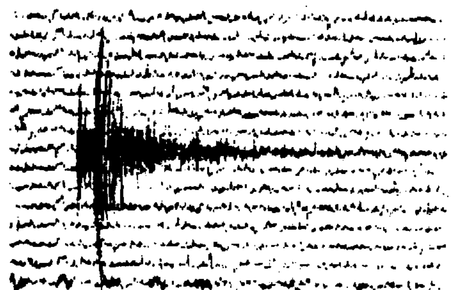


Elberton Quarry
9 October 1981 Station EP1
Time: 17:30:25 S-P=4.2 sec

Figure 8I.

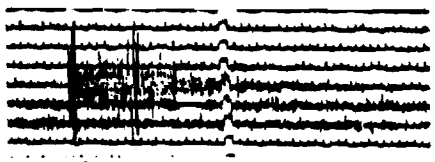


New blast site above Elberton
10 November 1981   Station BEV
Time: 18:27:02   S-P=1.9 sec

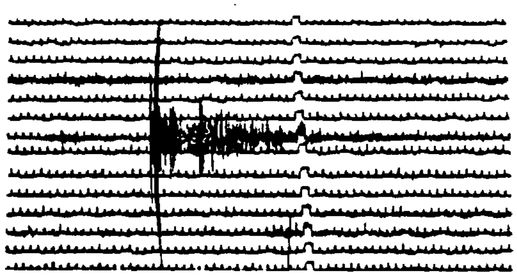


New blast site above Elberton
10 November 1981   Station LDV
Time: 18:27:03   S-P=2.4 sec

Figure 8J.



Heardmont
15 December 1981 Station BEV
Time: 17:06:39.9 S-P=0.6 sec



Heardmont
15 December 1981 Station LDV
Time: 17:06:39.4 S-P=0.8 sec

Figure 8K.

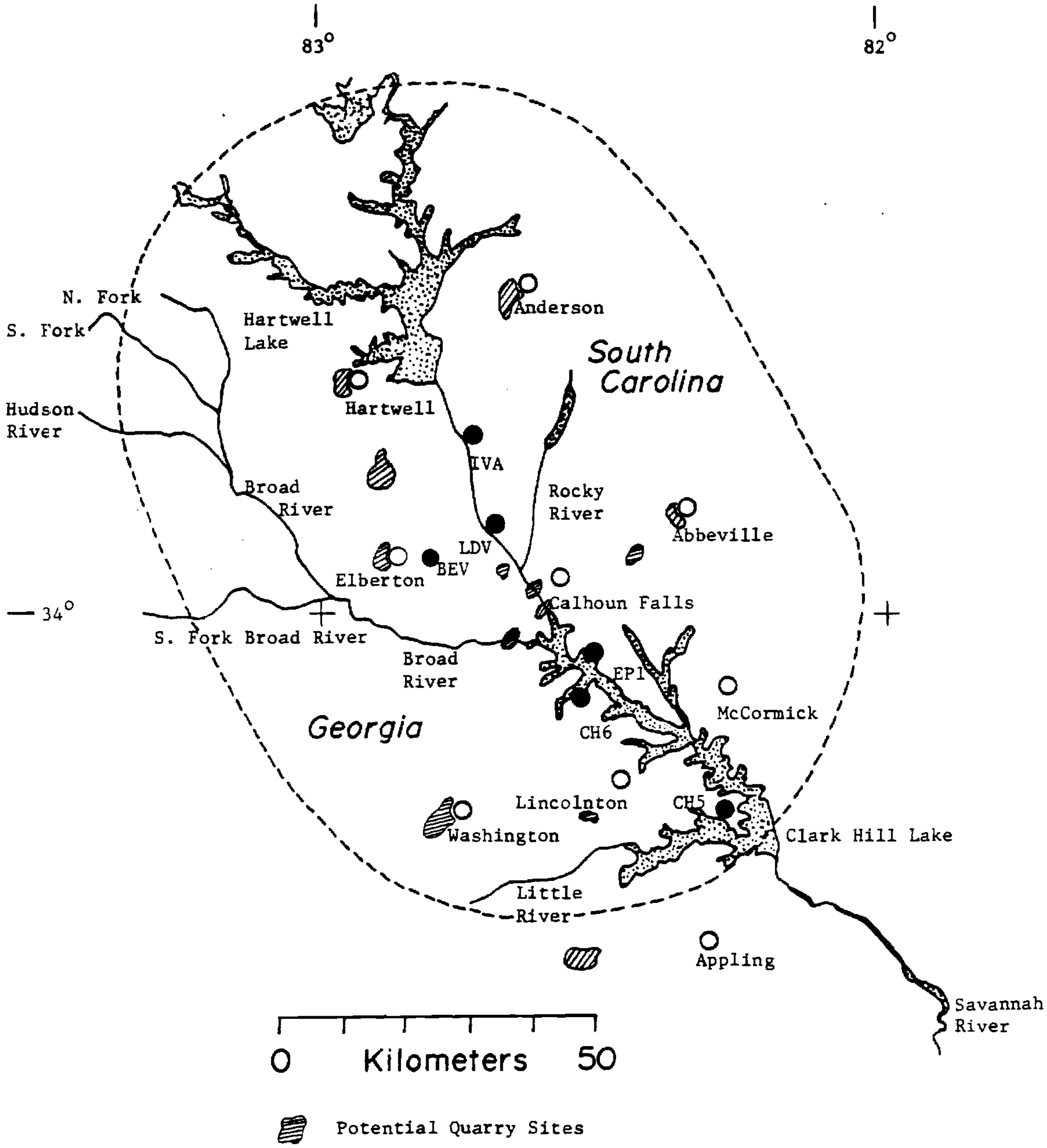
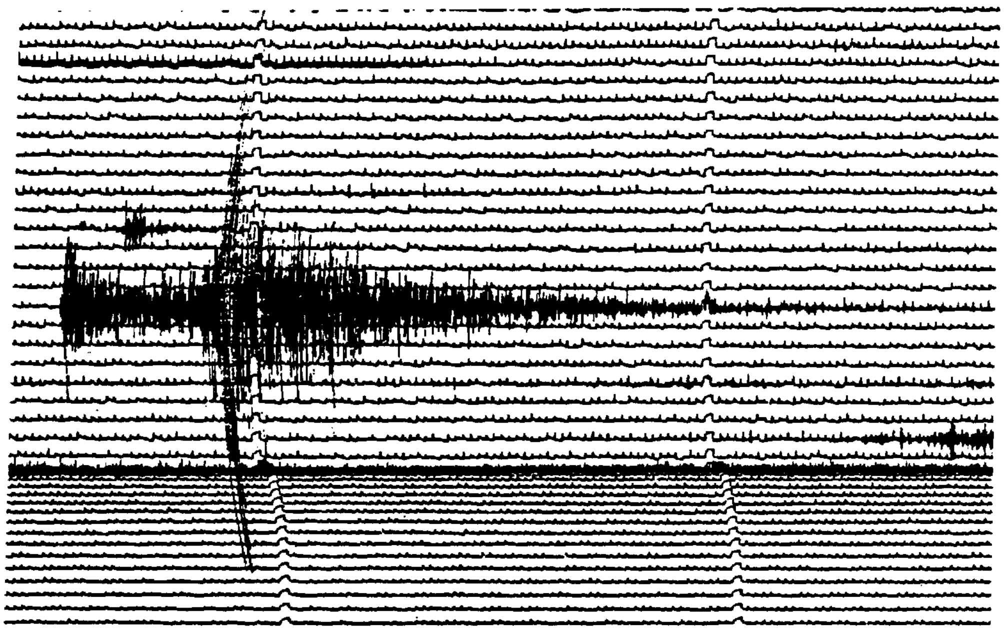
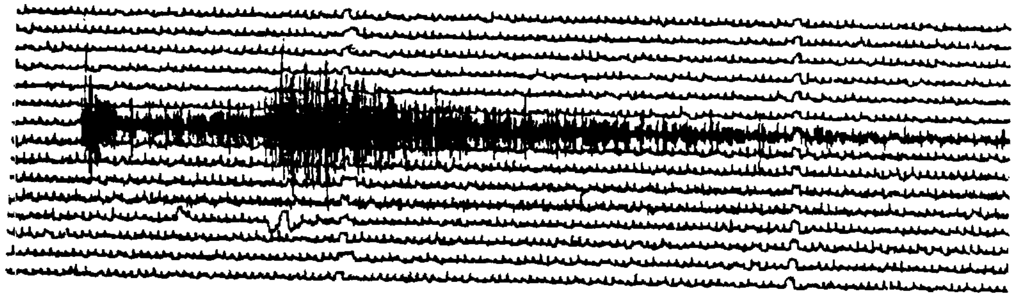


Figure 9. Area of investigation and locations of quarries active during the first period of operation of the Seismic Net.



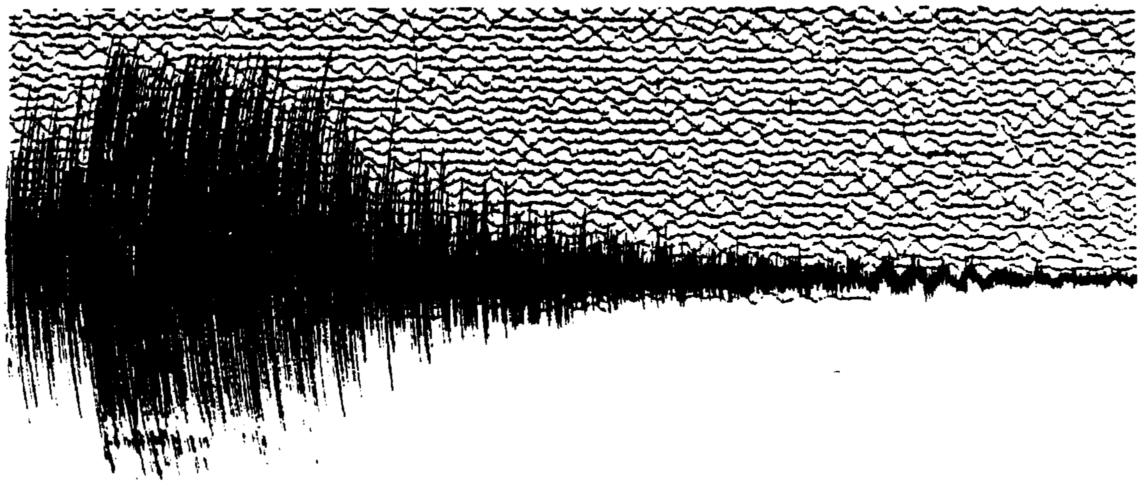
16 January 1983
Location: Macon, GA
Origin Time: 02:06:08

Station PLG 02:06:35
BEV SLG 02:06:55



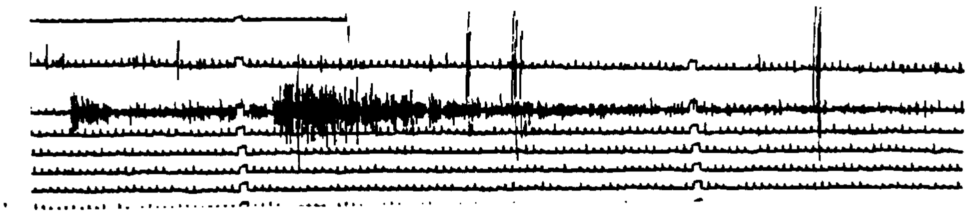
16 March 1983
Location: Reliance, TN
Origin Time: 09:13:52.5

Station PLG 09:14:25.5
LDV SLG 09:14:50



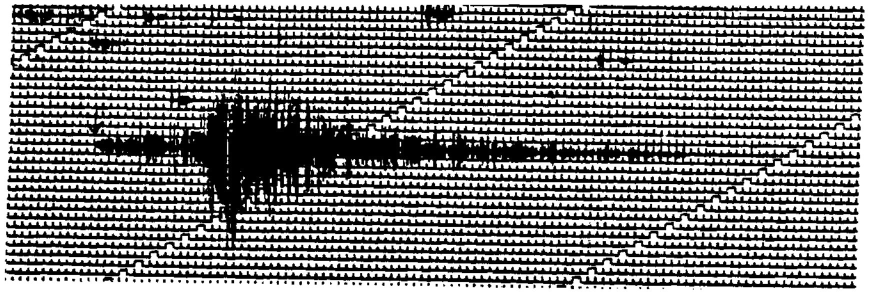
25 March 1983
Location: SC - NC Border
Origin Time: 02:47:12.57

Station: IVA



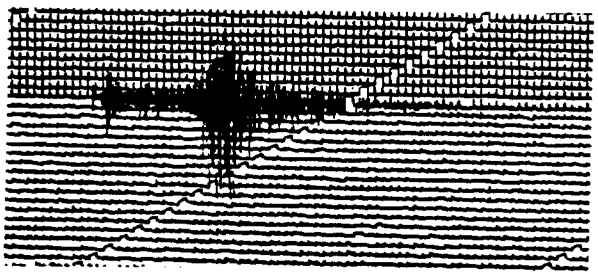
25 May 1983
Location: Greenback, TN
Origin Time: 12:29:40.2

Station	PLG	12:30:38
BEV	SLG	12:31:05



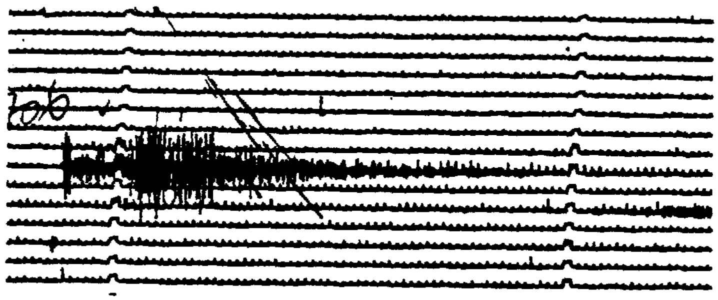
17 June 1983
Location: NE of Macon, GA
Origin Time: 04:11:07

Station	PLG	04:11:28
CH5	SLG	04:11:42



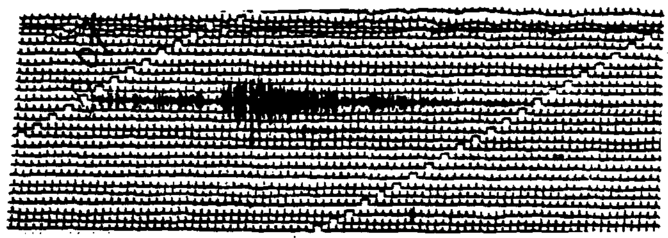
NE of Macon, GA

Station	PLG	04:11:27
CH6	SLG	04:11:42



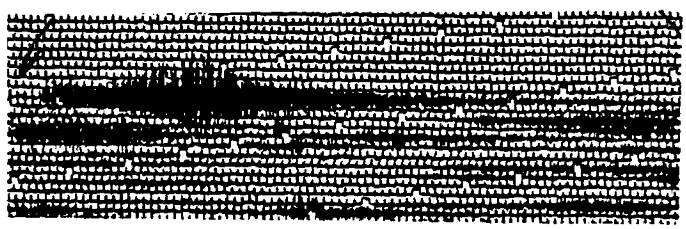
07 July 1983
Location: Lake Keowee, SC
Origin Time: 07:06:49

Station PLG 07:06:52.5
LDV SLG 07:07:02



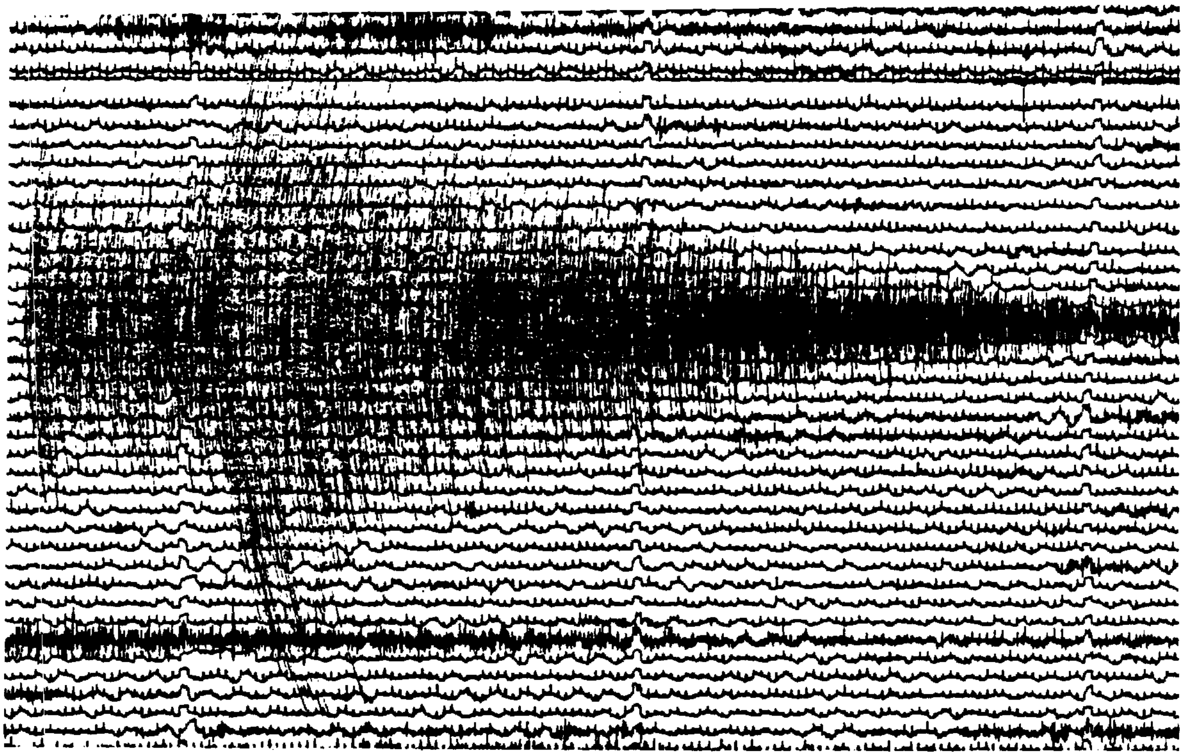
Lake Keowee, SC

Station PLG 07:07:02.5
CH5 SLG 07:07:18.5



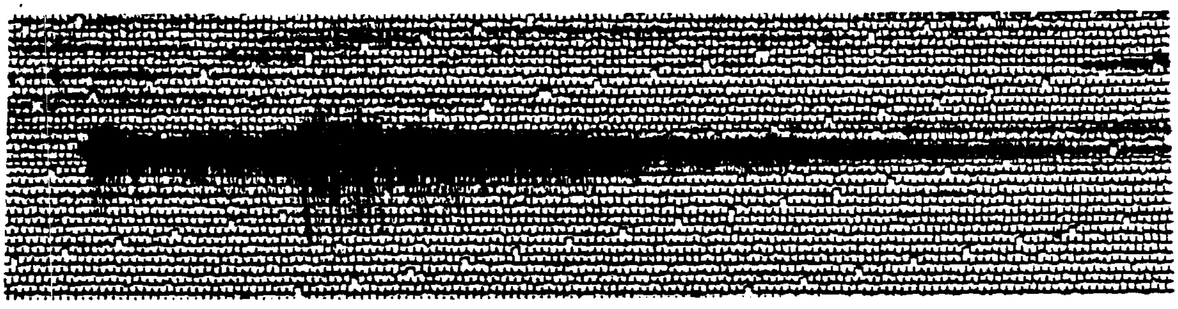
Lake Keowee, SC

Station PLG 07:06:58
CH6



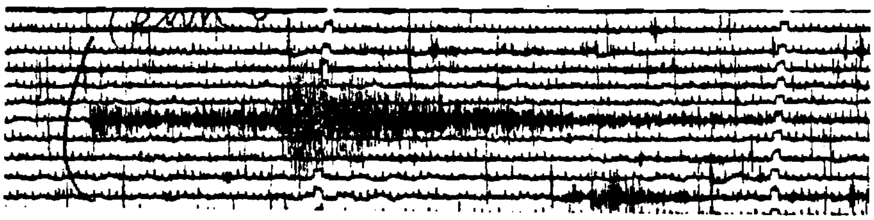
08 July 1983
Location: Tellico Plains, TN
Origin Time: 19:29:06.5

Station PLG 19:29:39.5
BEV SLG 19:30:04



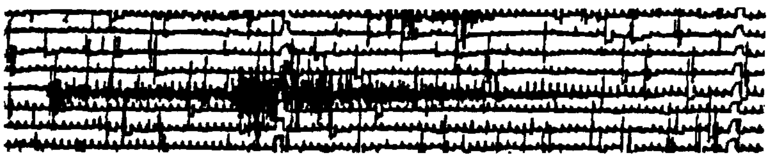
Tellico Plains, TN

Station PLG 19:29:42.6
CH6 SLG 19:30:11



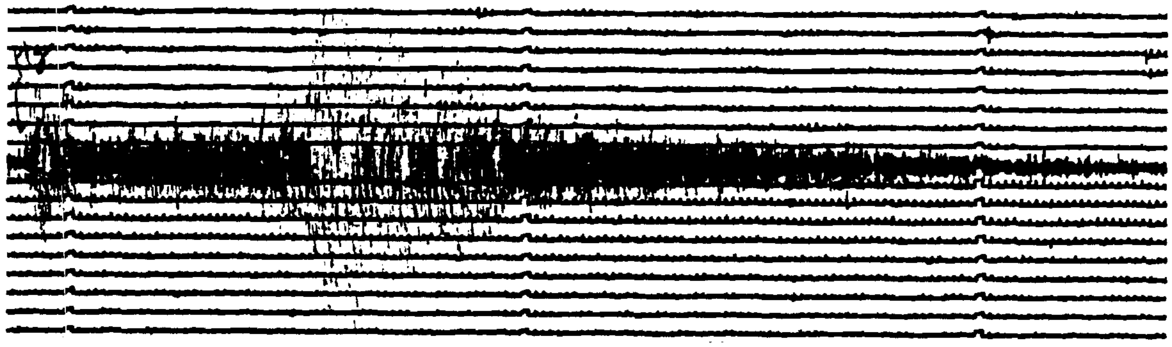
15 July 1983
Location: Madisonville, TN
Origin Time: 19:32:56.4

Station	PLG	19:33:30
BEV	SLG	19:33:55



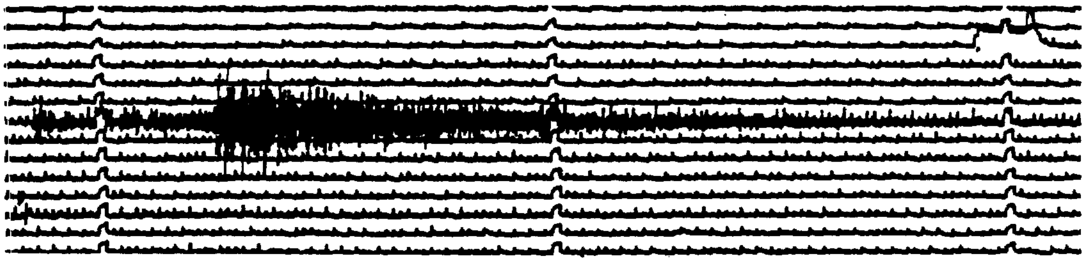
Madisonville

Station	PLG	19:33:29.5
LDV	SLG	19:33:53.8



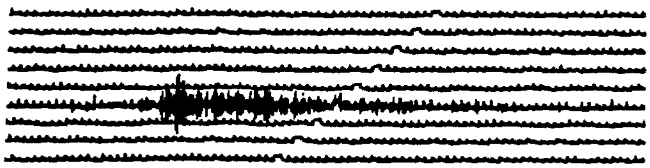
28 August 1983
Location: Tennessee
Origin Time: 22:30:05.3

Station	PLG	22:30:55
BEV	SLG	22:31:32



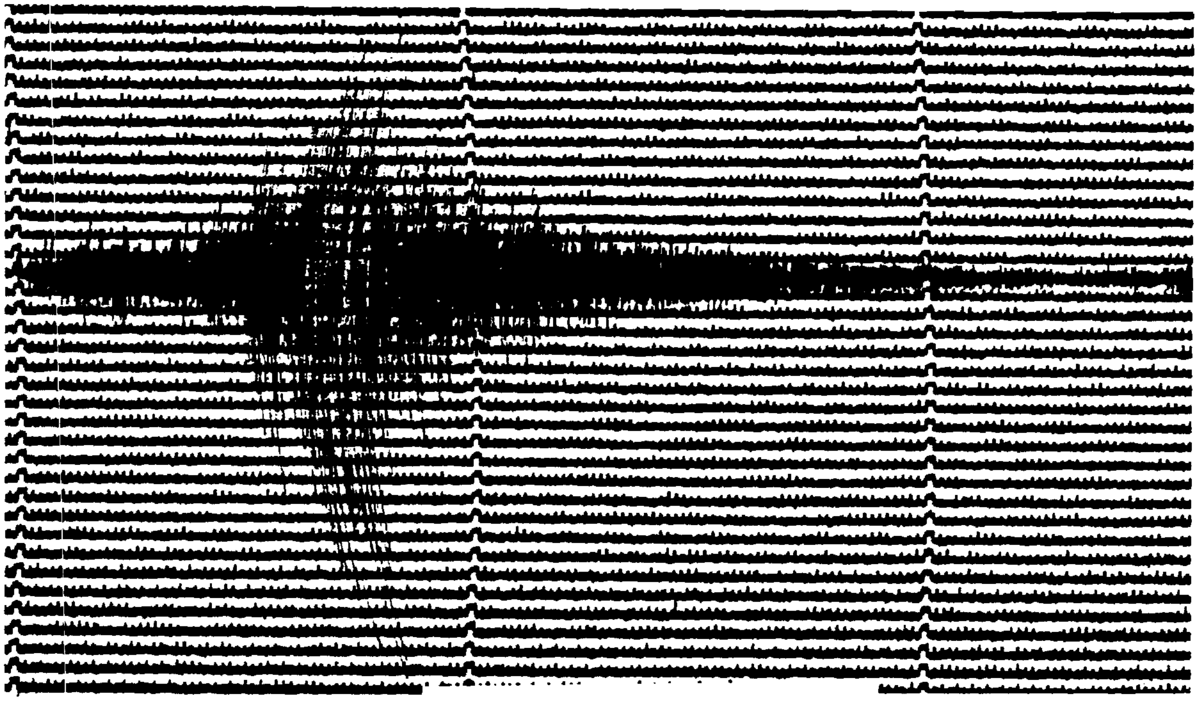
17 October 1983
Location: Citico Beach, TN
Origin Time: 07:45:19.5

Station	PLG	07:45:51.6
IVA	SLG	07:46:15.5



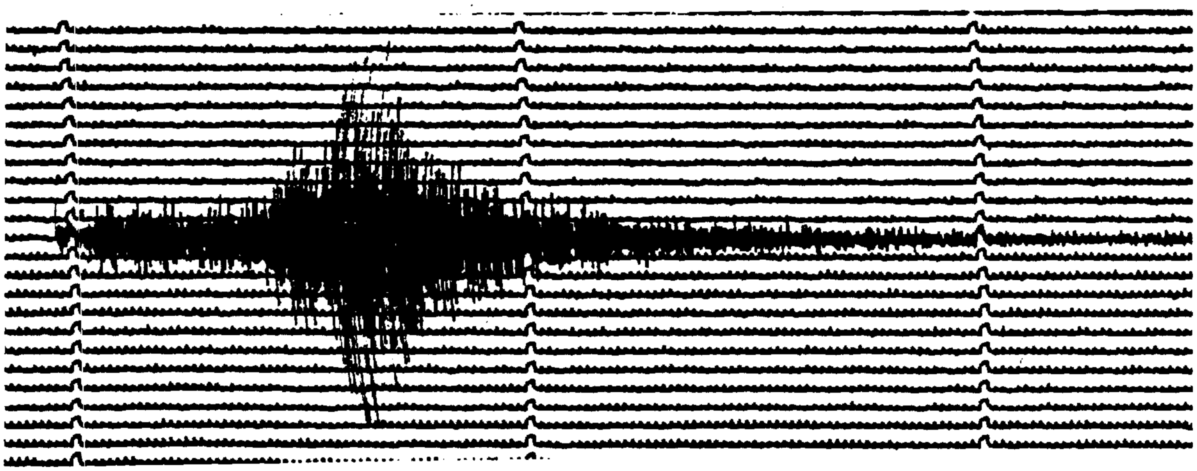
Citigo Beach, TN

Station	PLG	07:46:24.0
CH5	SLG	07:46:36.6



06 November 1983
Location: Charleston, SC
Origin Time: 09:02:51

Station PN 09:03:00
IVA SN 09:03:31



Charleston, SC

Station PN 09:02:59
LDV SN 09:13:34.5

Table 1. Station Operation Periods

Month	IVA	BEV	LDV	One Station Coverage	Two Station Coverage	Three Station Coverage
January	54%	59%	71%	71%	51%	31%
February	93%	3%	96%	100%	93%	3%
March	51%	39%	74%	90%	52%	22%
April	87%	81%	90%	100%	86%	32%
May	22%	84%	74%	92%	66%	21%
June	0%	88%	93%	96%	85%	0%
July	0%	80%	89%	95%	74%	0%
August	0%	70%	55%	99%	28%	0%
September	13%	88%	86%	89%	87%	12%
October	66%	8%	68%	77%	64%	0%
November	98%	0%	99%	99%	98%	10%
December	86%	68%	71%	94%	79%	52%
Average Coverage Over 12 Months	48%	56%	81%	92%	72%	15%

Explanation of Station Coverage

Station coverage is broken down as follows:

One Station Coverage - the percentage of time that at least one of the three stations is functioning normally.

Two Station Coverage - the percentage of time that at least two of the three stations are functioning normally.

Three Station Coverage - the percentage of time that all three stations are functioning normally.

Appendix I

Equipment assignments for IVA

Amplifier	419	VCO Frequency	1360
Pulse Calibrator	164	Gain	66dB
Geophone	766	Filter low cut	0.2 Hz
Recorder	390	Filter high cut	25 Hz

The location of the telephone pole is indicated in the map. It is numbered E-1-37.

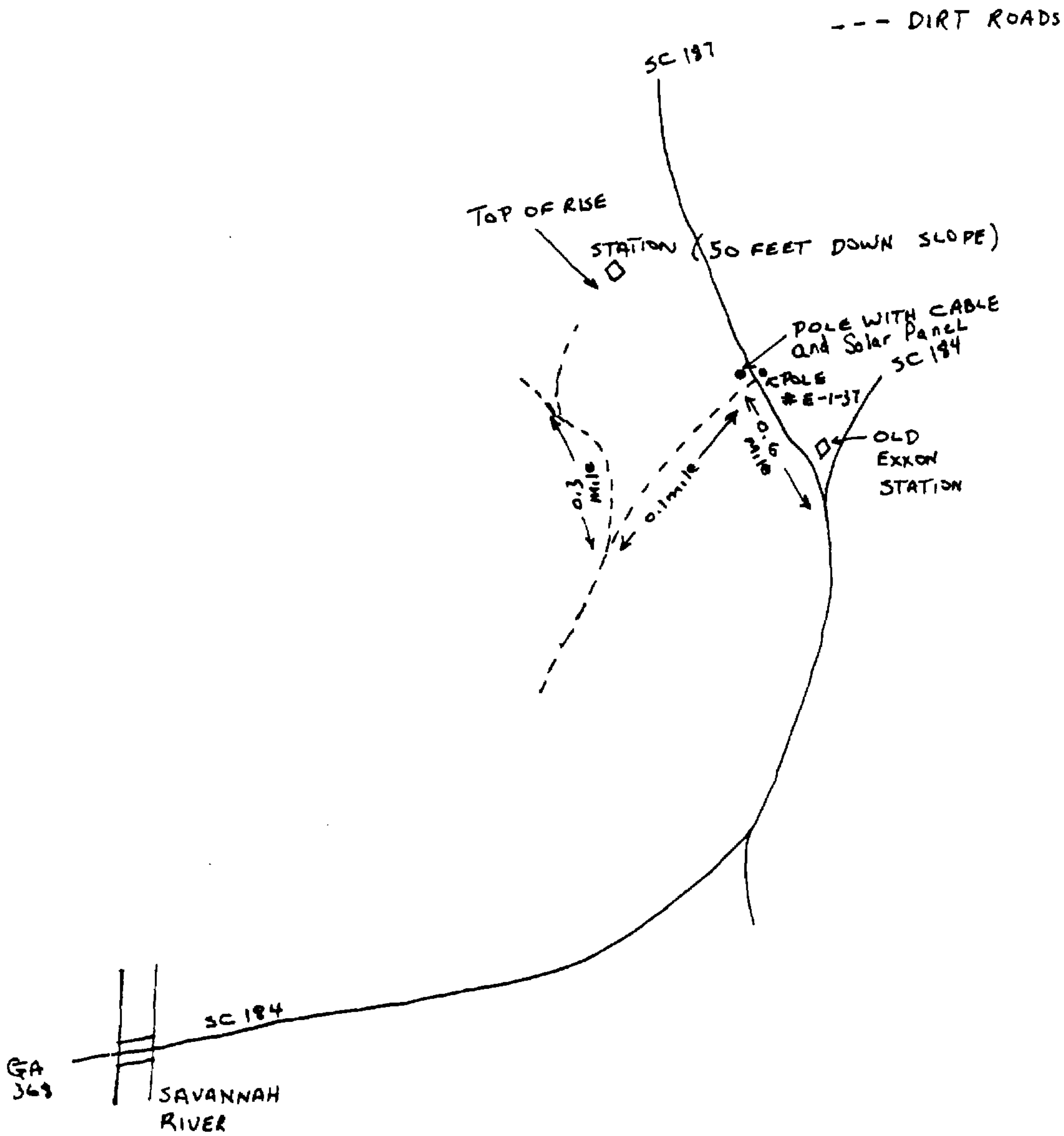
Vault Location

Latitude	34.2721°N
Longitude	82.7460°W
Elevation	0.1676 km

The property is owned by the U. S. Army Corps of Engineers.

Directions to IVA:

From downtown Elberton take N. Oliver Road toward South Carolina. This road intersects with Georgia 368. There is an old gas station at the intersection. Take a right here. The road crosses the Savannah River and becomes S.C. 184. 184 forks into 184 and 187. Take the road to the left (187) and continue for 0.6 mile. A dirt road runs to the left here. Take it and turn right at the next dirt road. This road forks. Take the right fork. This will go to the edge of a hill. A worn path down on the right runs into the cable which can be followed down the hill to the station.



Directions to IVA (Continued)

Appendix I (Continued)

Equipment assignments for LDV

Amplifier	348	VCO Frequency	680
Pulse Calibrator	165	Gain	66dB
Geophone	768	Filter low cut	0.2 Hz
Recorder	386	Filter high cut	25 Hz

The location of the telephone pole is indicated in the map.

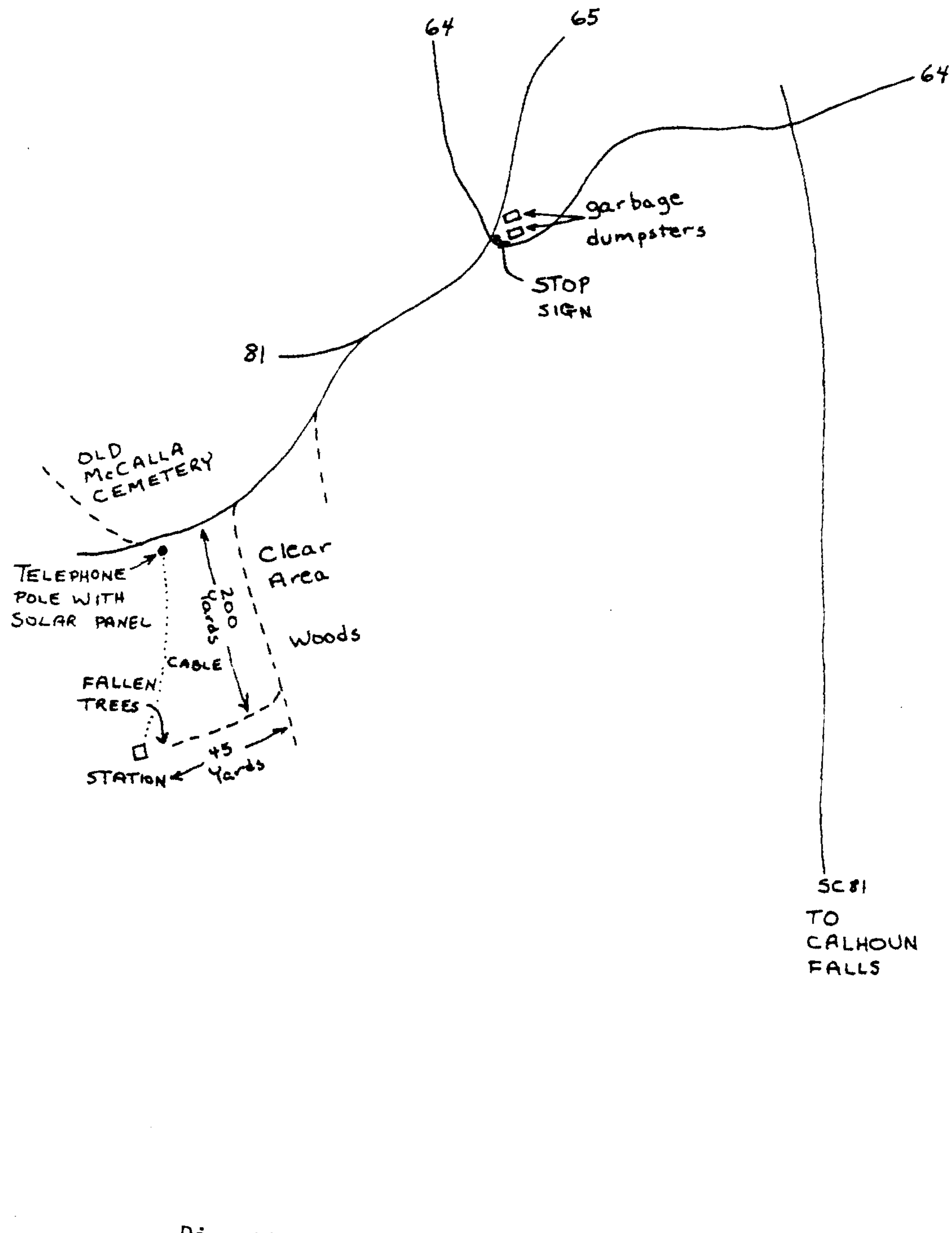
Vault Location

Latitude	34.148°N
Longitude	82.6833°W
Elevation	0.1615 km

The property is owned by the U. S. Army Corps of Engineers.

Directions to LDV:

From Calhoun Falls take S.C. 81 north until it intersects with S.C. 64. Turn left onto 64 and cross the river (a future lake) and proceed to the stop sign. At the intersection turn left onto S.C. 65. Stay on 65 passing a fork to the right until the road forks into a dirt road to the left and a paved road to the right. This road runs through an open area of tall hardwood trees. Take the dirt road to the left that passes through these woods. Up this road about 200 yards another road which may be slightly overgrown runs to the right. Stop here, and follow the road through the woods on foot. The station is behind some fallen trees at the end of the road.



Directions to LDV (Continued)

Appendix I (Continued)

Equipment assignments for BEV

Amplifier	306	VCO	Frequency	240
Pulse Calibrator	163		Gain	66dB
Geophone	767		Filter low cut	0.2 Hz
Recorder	391		Filter high cut	25 Hz

Location of the telephone pole:

Proceed north on Georgia Highway 245 from Georgia 72. The cable is tied to a pole as indicated on the site map. The pole is numbered No. 8P and is the third or fourth pole from the dumpster.

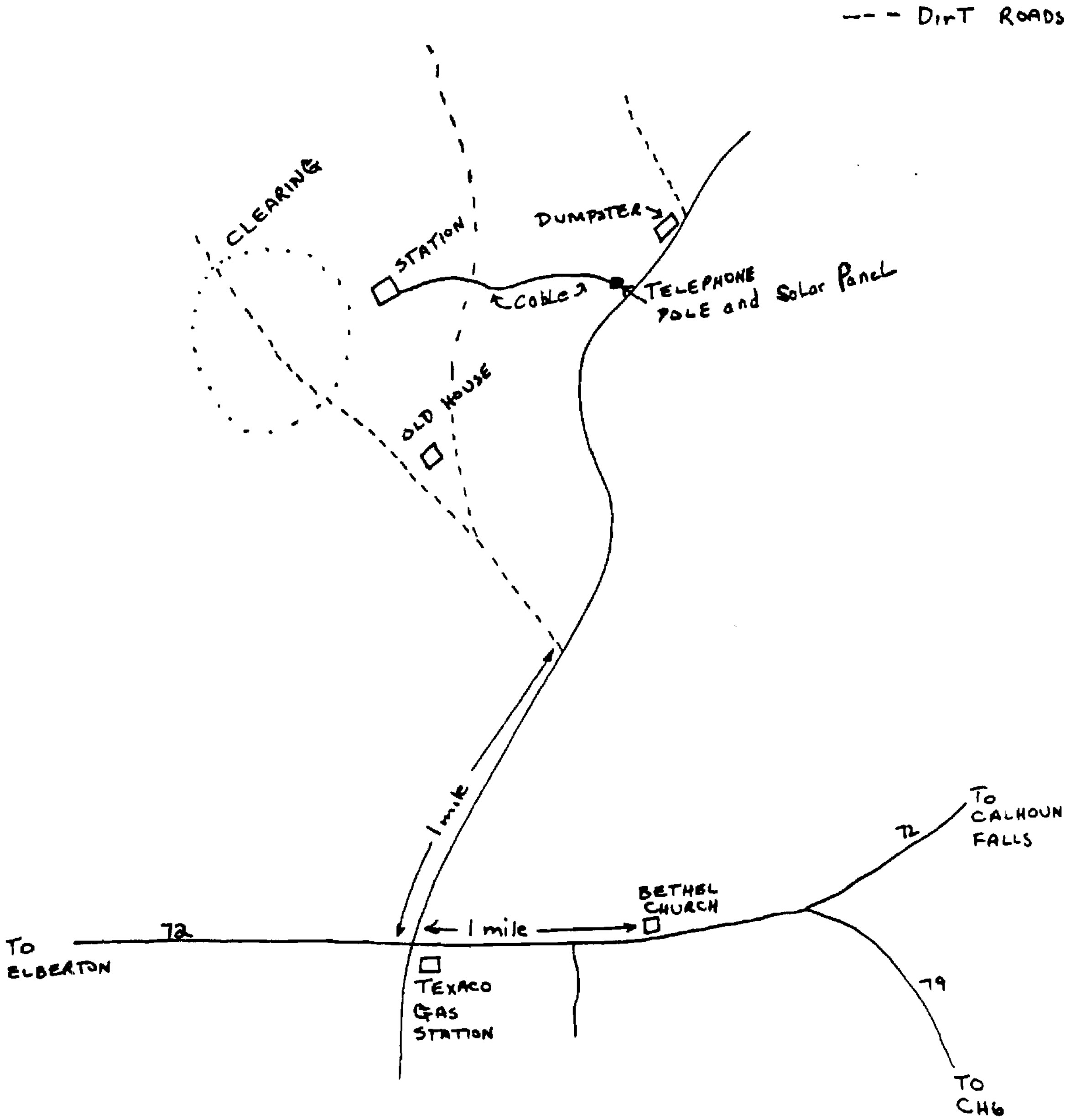
Vault Location

Latitude	34.0893°N
Longitude	82.7334°W
Elevation	0.1584 km

The property is owned by the U. S. Army Corps of Engineers.

Directions to BEV:

From Elberton take Highway 72 westward through Middleton. There will be a Texaco station and a mini-market on the right. Make a left turn at the Texaco station. Take this road for about 0.95 miles. Take the dirt road here which forks to the left. This road will in turn fork to the right and left. Take the left fork. This road will run through a clearing about 100 yards in diameter. The station is on the right side about 50 feet from the edge of the open area.



Directions to BEV (Continued)

ANNUAL REPORT NO. 5
PROJECT NO. G-35-622

MICROEARTHQUAKE INSTRUMENTATION AND ANALYSIS BETWEEN HARTWELL AND CLARK HILL RESERVOIR AREAS

Annual Technical Report for Period 1 January 1984 - 31 December 1984

By

Dr. Leland Timothy Long
Professor of Geophysics
and
Russell Propes
Graduate Research Assistant

Prepared for

U. S. ARMY CORPS OF ENGINEERS
Savannah District
P.O. Box 889
Savannah, Georgia 31402

Issued February 1985

GEORGIA INSTITUTE OF TECHNOLOGY
A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA
SCHOOL OF GEOPHYSICAL SCIENCES
ATLANTA, GEORGIA 30332

1985

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MICROEARTHQUAKE INSTRUMENTATION AND ANALYSIS
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INTRODUCTION

The Richard B. Russell Lake now covers the Savannah River valley in the Piedmont Province of Georgia and South Carolina from the headwaters of the Clark Hill Reservoir north to Hartwell Dam. Impoundment of the Savannah River was initiated in December 1983. While most reservoirs do not trigger microearthquakes when they are first impounded, there is evidence that some reservoirs in the Piedmont Province of South Carolina and Georgia have induced seismic activity. The objective of the microearthquake instrumentation and the analysis of data on events occurring between the Hartwell and Clark Hill Reservoirs Areas is to document the seismicity prior to, during, and after impoundment of the Richard B. Russell Lake. This report covers the maintenance of the seismic monitoring system from 1 January 1984 to 31 December 1984.

SEISMICITY

The earthquakes observed in the Piedmont Province (Figure 1) occur at scattered locations with little apparent correlation with major geologic structures. Where reliable estimates of their depth are available, the implied depths are shallow and are typically less than two kilometers deep. The largest, the Union County earthquake of 1913, was, perhaps, a magnitude 5.5. The rate of activity is low, with an average of one event greater than magnitude 3.5 occurring less than once every four years in South Carolina and Georgia. Today, the seismicity at magnitudes less than 2.0 is difficult to assess because the shallow focus earthquakes typical of the Piedmont Province generate signatures similar to the signatures of industrial explosions in the many quarries which mine the near-surface crystalline rocks. The seismic monitoring system will detect earthquakes or blasts less than magnitude zero. Hence, an initial objective of the analysis of seismic monitoring data between Hartwell and Clark Hill Reservoir Areas is to identify the active quarries and other industrial blast sites in order to properly assess the background level of seismicity.

The area of the Richard B. Russell Lake does not exhibit any historical seismicity, although the area has experienced disturbances from more distant events, such as the 1886 Charleston earthquake and the Clark Hill vicinity earthquakes. The two closest epicenters based on currently available data are near Due West and McCormick, South Carolina. Due West is approximately 40 km east of the Savannah River and experienced earthquakes in 1929, 1930, 1931, and 1956. The earthquake near McCormick occurred August 2, 1974. On November 1, 1875, a maximum intensity VI (mm) earthquake was noted in the Clark Hill

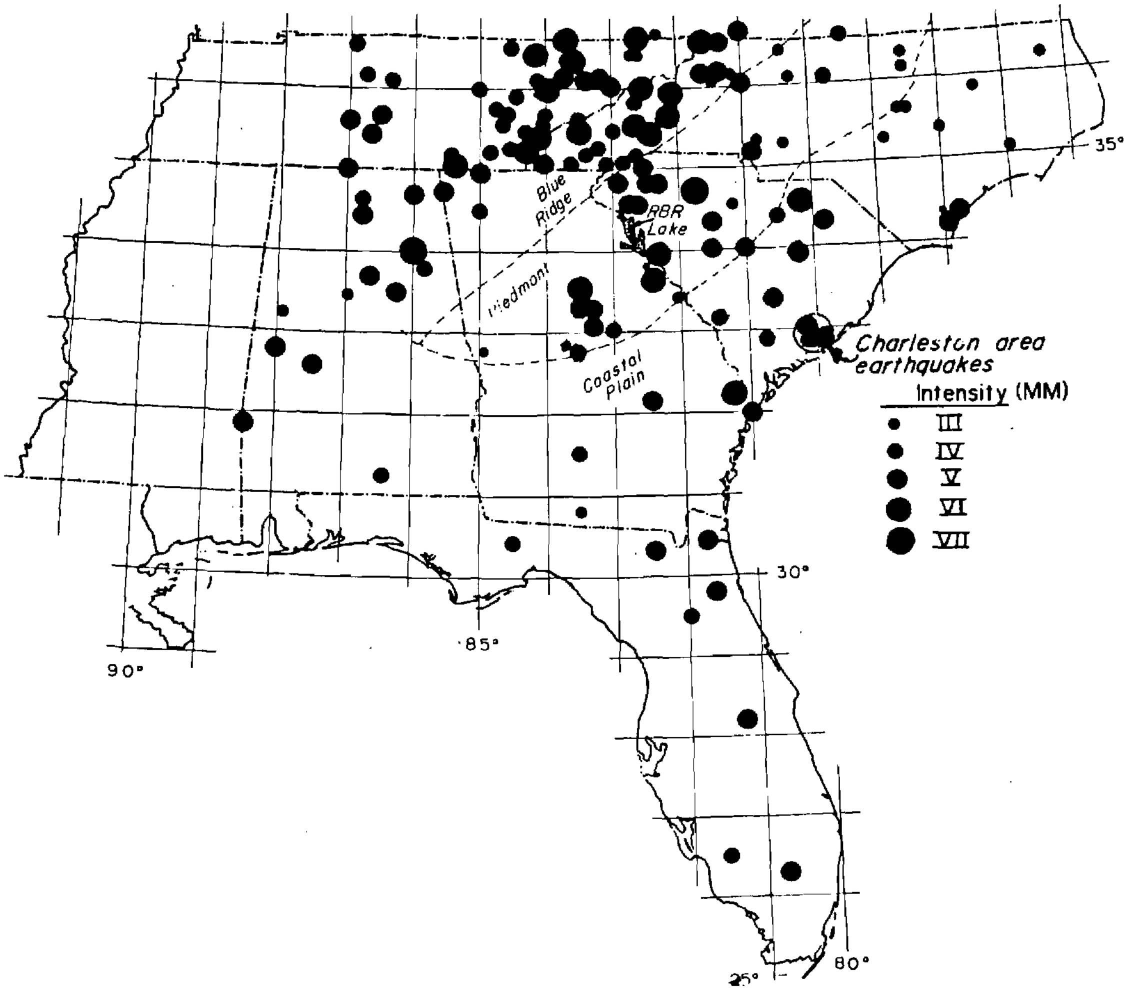


Figure 1. Seismicity of the southeastern United States and its relation to the proposed Richard B. Russell (RBR) Lake. After Bollinger (1973)

Reservoir Area near Lincolnton, Georgia. These two events occurred 10 to 20 km south of the Richard B. Russell Dam site.

Many of the recent earthquakes in the Piedmont Province have epicenters near reservoirs. These include the Seneca earthquake on July 13, 1971; the Jocassee earthquakes of 1975, 1976, and 1979; and the August 2, 1974, McCormick earthquake. Monticello Reservoir north of Columbia, South Carolina, triggered an extensive sequence of small (magnitude 2.5 to 3.0) earthquakes. Lake Sinclair, Georgia, has exhibited a continuous sequence of events, although the reservoir was impounded in the '50's and the association with the reservoir is tenuous. Lake Oconee, impounded in the spring of 1979, generated only a short sequence of small (less than M = 0) events in the spring of 1980. The Oconee reservoir events would not have been noted without a sensitive seismic net. Hence, one can speculate that other reservoirs similarly triggered events, but these events were undetected. In the case of Monticello and Oconee, seismic monitoring was available prior to loading and no significant seismic activity was detected in the vicinity of the forthcoming reservoirs. While at present the pre-impoundment seismicity does not allow predictions of induced earthquakes, it can provide valuable data concerning the occurrence of natural seismic activity.

The Richard B. Russell Lake now covers a 130 sq-km area of the Piedmont Province, an area in which nearby reservoirs are associated with induced seismic activity. Hence, the probability is high that Richard B. Russell Lake may induce some seismic activity. If seismic activity is induced near the Richard B. Russell Lake, the earthquakes will most likely be small, generally unfelt, and less than magnitude 2.5. Earthquakes with magnitudes as large as 3.5 are not common near Piedmont Province reservoirs (only two events with magnitudes greater than 3.2 occurred at Jocassee) and magnitudes larger than 4.5 are highly unlikely. Earthquakes could conceivably be induced anywhere near the reservoir. An objective of the seismic monitoring is to locate sites of activity should they develop after impounding the reservoir. Because their depths are expected to be shallow, perhaps as shallow as 0.5 to 1.5 km, the widely spaced net cannot determine accurate depths of focus. Instead, portable equipment would be deployed with appropriate spacing to compute depths of focus for events in selected active areas.

SEISMIC NET

The Richard B. Russell seismic net consists of four vertical-component short-period seismic systems. The four stations (see Figure 2) form a network elongated in the north-south direction. The four sites are furnished and maintained by the Savannah District Corps of Engineers. Maintenance of the microearthquake monitoring system is provided through the mutual support of Georgia Tech and the Savannah District Corps of Engineers. Georgia Tech and the Savannah District Corps of Engineers also agree to the mutual use of the microearthquake

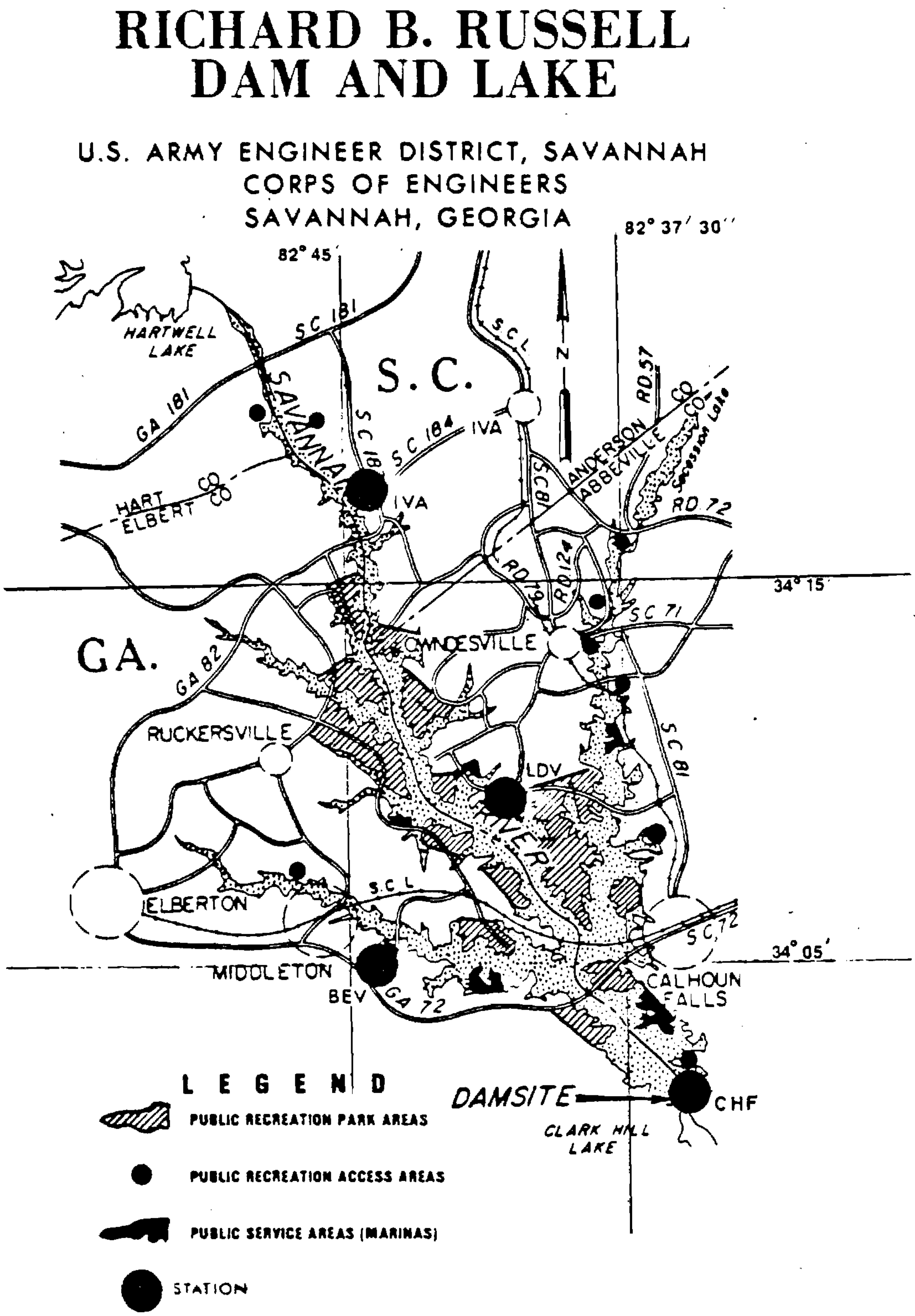


Figure 2. Location map for the four station Richard B. Russell Lake Seismic Net.

monitoring system in the area between Hartwell and Clark Hill Reservoirs. Use of the data is confined to non-profit research. Requests for the usage of the data can be submitted directly to Georgia Tech. However, Georgia Tech must forward all requests to the Savannah District Corps of Engineers for approval. A brief report describing the data usage, the seismic events, and copies of the appropriate events shall be submitted to the Savannah District Corps of Engineers.

The designation for the northernmost station is IVA because it is 8 km west-southwest of Iva, South Carolina. IVA is within 1.0 km of the Savannah River and 13 km southeast of Hartwell Lake. Station LDV is 8 km south-southwest of Lowndesville, South Carolina, and 15 km northwest of the Richard B. Russell Dam site, at the headwaters of Clark Hill Reservoir. Station BEV is near the former town of Beverly, Georgia, and 14 km west-northwest of the dam site. Station CHF is south of the town of Calhoun Falls, Georgia, and just east of the Richard B. Russell Dam site. Detailed descriptions of the locations of the four stations IVA, LDV, BEV, and CHF are given in Appendix I.

The regional distribution of seismic stations is shown in Figure 3. Station CHF is about 1.0 km east of the Richard B. Russell Dam site. Station CHF was originally funded by the Savannah District Corps of Engineers and eventually installed by the U.S. Geological Survey. The station originally consisted of one vertical and one horizontal short-period seismometer. The data were telemetered to Columbia, South Carolina, where they were recorded on a helical recorder. Station CHF did not operate during 1983. Reinstallation as a single vertical component was completed in January 1984 as a part of the Richard B. Russell seismic network. Station PRM on Parsons Mountain is part of the South Carolina Seismic Net operated by the U.S. Geological Survey. Stations EP1, CH5, and CH6 in the Clark Hill area are operated by Georgia Tech with the support of the Nuclear Regulatory Commission. At Georgia Tech, the Clark Hill stations are combined with the three Richard B. Russell stations to form a 75 km linear array. Additional seismic coverage to the north is provided by station SMT operated by Duke Power and the University of South Carolina. To the south, the Savannah River Plant operates a three-station array. To the southeast, station MTT, operated by the U.S. Geological Survey, is part of the South Carolina Net.

INSTRUMENTATION

Components for the microearthquake monitoring system were provided by the Savannah District Corps of Engineers. The system was assembled and installed by Georgia Tech. The specifications and construction of the system were made uniform in order to provide uniform response characteristics.

A vault was constructed to house the instruments in the field (see Figure 4). The vault was designed to provide a 10 to 20 cm thick cement base on which to rest the geophone. Sites were chosen to allow

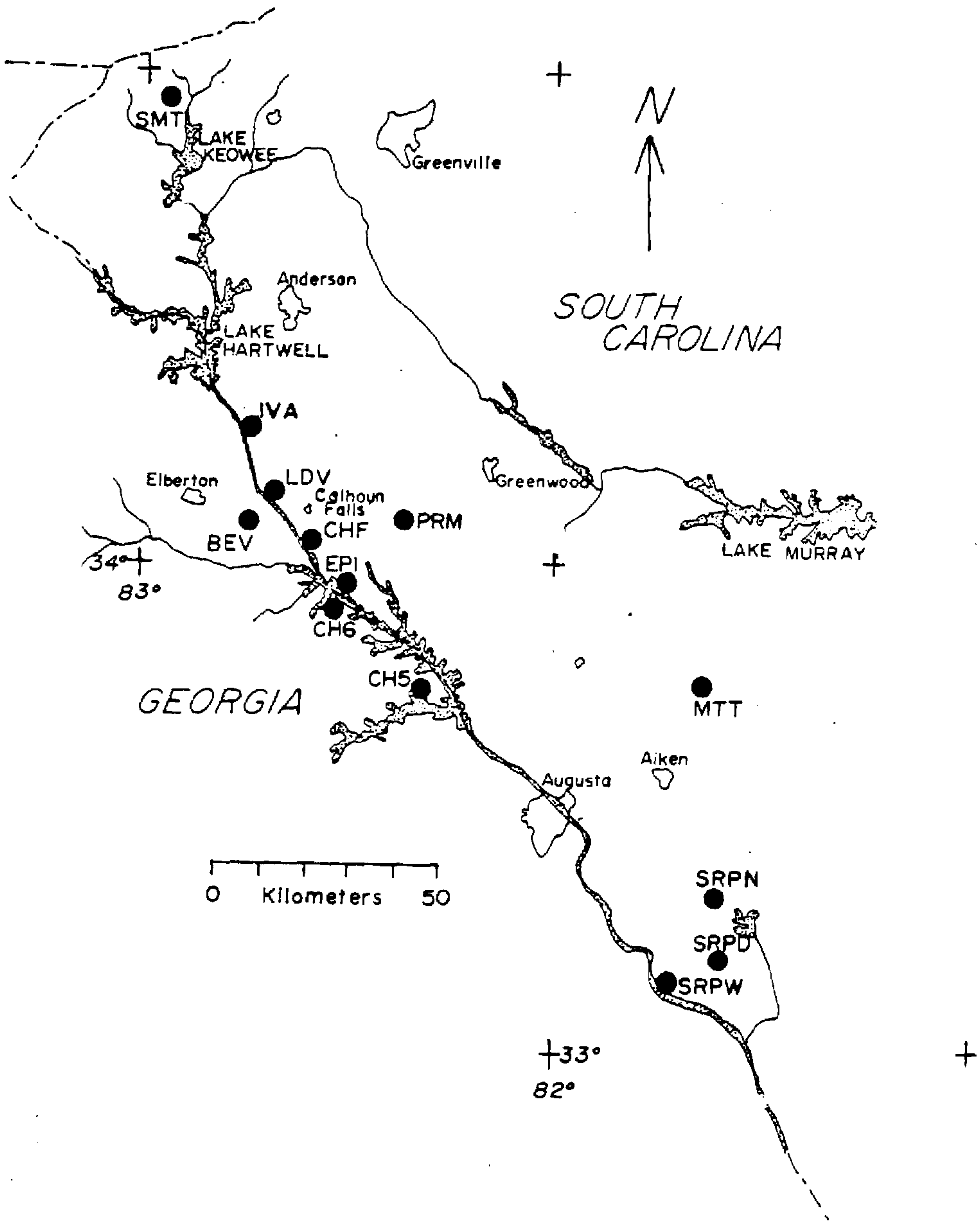


Figure 3. Location of seismic stations along the Savannah River

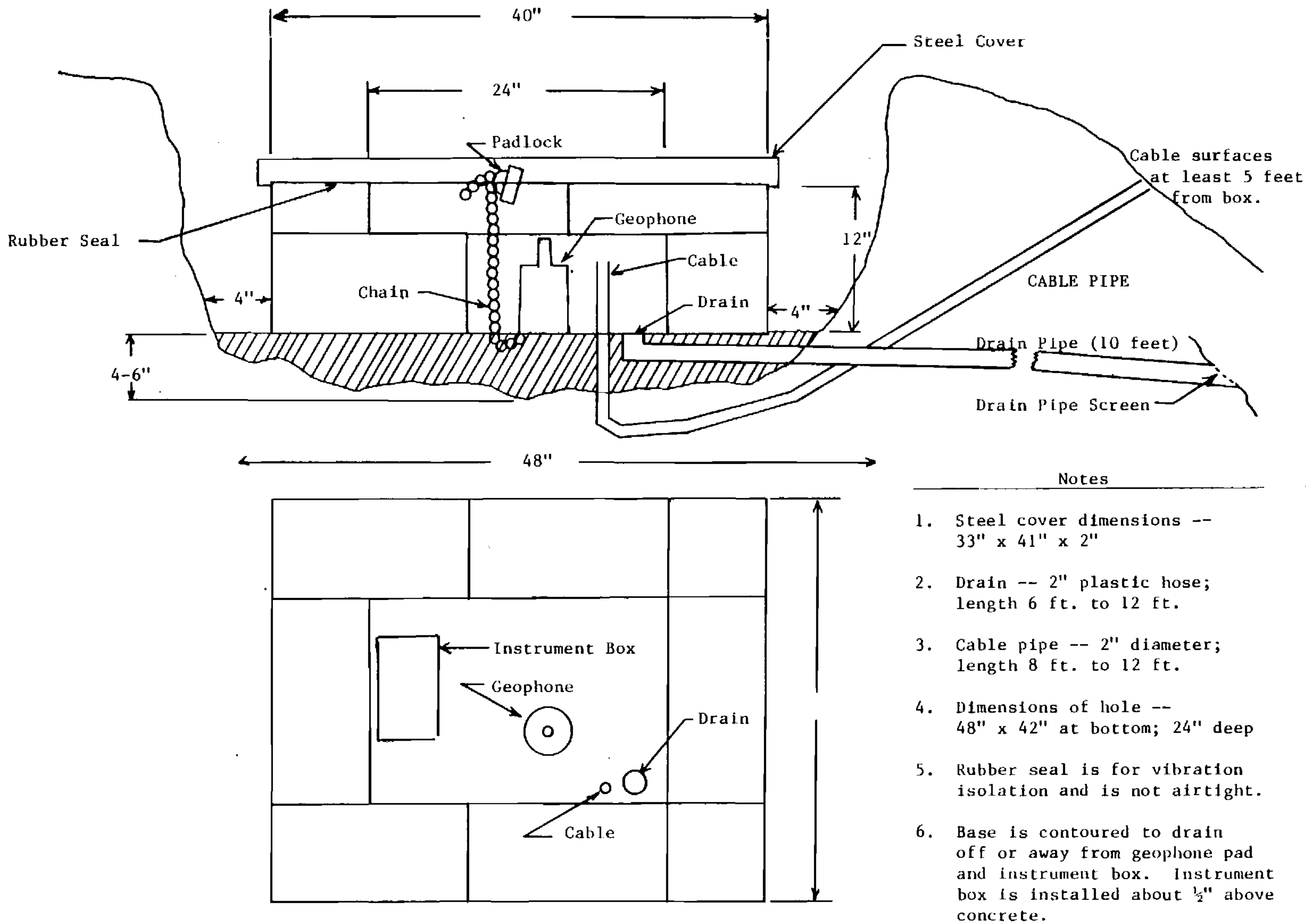


Figure 4. Specifications for the seismic vaults built for the Richard B. Russell Seismic Net.

placement of the cement pad as close to bedrock as possible, and on a sufficient slope to guarantee drainage. Cinder blocks were used to build the walls and the top was covered by a welded iron cover. The design provides for both drainage of water and circulation of air. The instruments are housed in separate weather-proof containers for their protection.

Figures 5 and 6 show the assembly of the field instrumentation, and Figure 7 shows the instrumentation used in the monitoring system at Georgia Tech. In 1983 radio frequency transmission to the radio tower at the Richard B. Russell Dam was installed in order to minimize phone line costs and lightning damage related to the connection of the equipment to the phone line. At the microwave tower the three RF transmitted signals are mixed with station CHF and transmitted to Georgia Tech via commercial telephone lines. At Georgia Tech, the telephone line signal is conditioned for proper impedance matching for the discriminators. The discriminator bank is designed for plug-in expansion from the existing three to seven possible stations. A patch cord system is used to route the discriminated signals to helical recorders. The timing system for the network is provided by means of a digital timing system at Georgia Tech and provides second, minute, hour, and twenty-four hour marks for the ink recorders.

DATA ANALYSIS

The objective of the data analysis is to review all records obtained from the microearthquake recording system and compute locations and magnitudes for earthquakes recorded by the system. Seismic activity occurring within the immediate vicinity of the reservoir, as defined by a 50 km radius from the Savannah River, will be reported to the Savannah District Corps of Engineers. Discrimination of earthquakes from local quarry blasts or construction explosions requires, in addition, that the principal active quarries be located and identified. In order to simplify the task of identifying quarry blasts and construction explosions, a catalog of common blasts as recorded at each station has been developed (Figures 8A - K). Through the use of this chart, a higher percentage of previously located blasts can be identified without requiring the careful measurement of phases for a computer location. This means also that a seismic event is less likely to be mistaken for a blast. Figure 9 identifies the area of investigation and the currently identified sites of explosions.

COVERAGE

The data analysis presented in this report covers the time period from 1 January 1984 to 31 December 1984. The average percent coverage over the twelve-month period was 90% for at least one station, 78% for two stations, 51% for three stations, and 17% for four stations. Table 1 gives a detailed monthly breakdown of coverage.

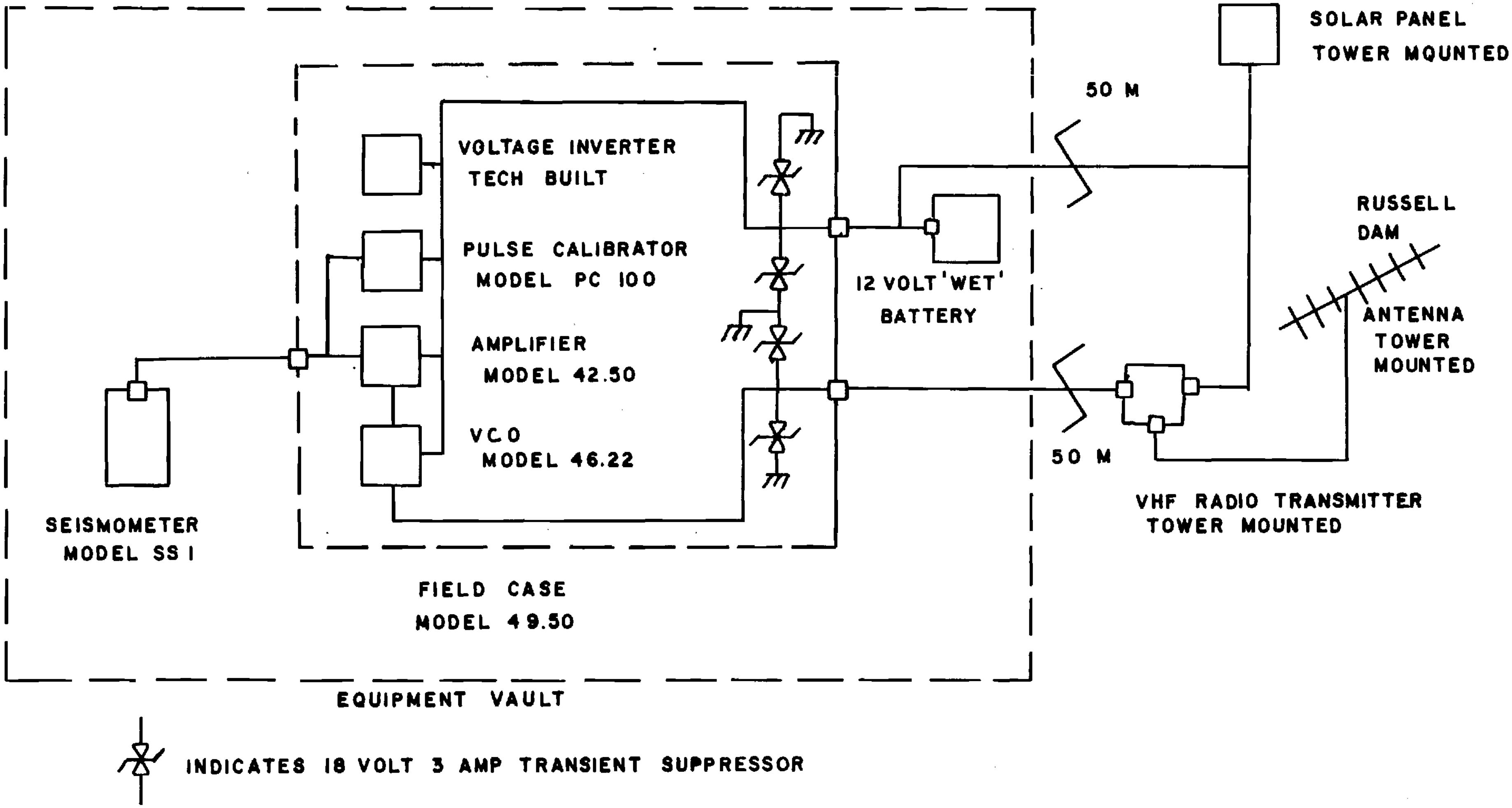


Figure 5. Field instrumentation design for the Richard B. Russell Seismic Network. Stations BEV, LDV, and IVA.

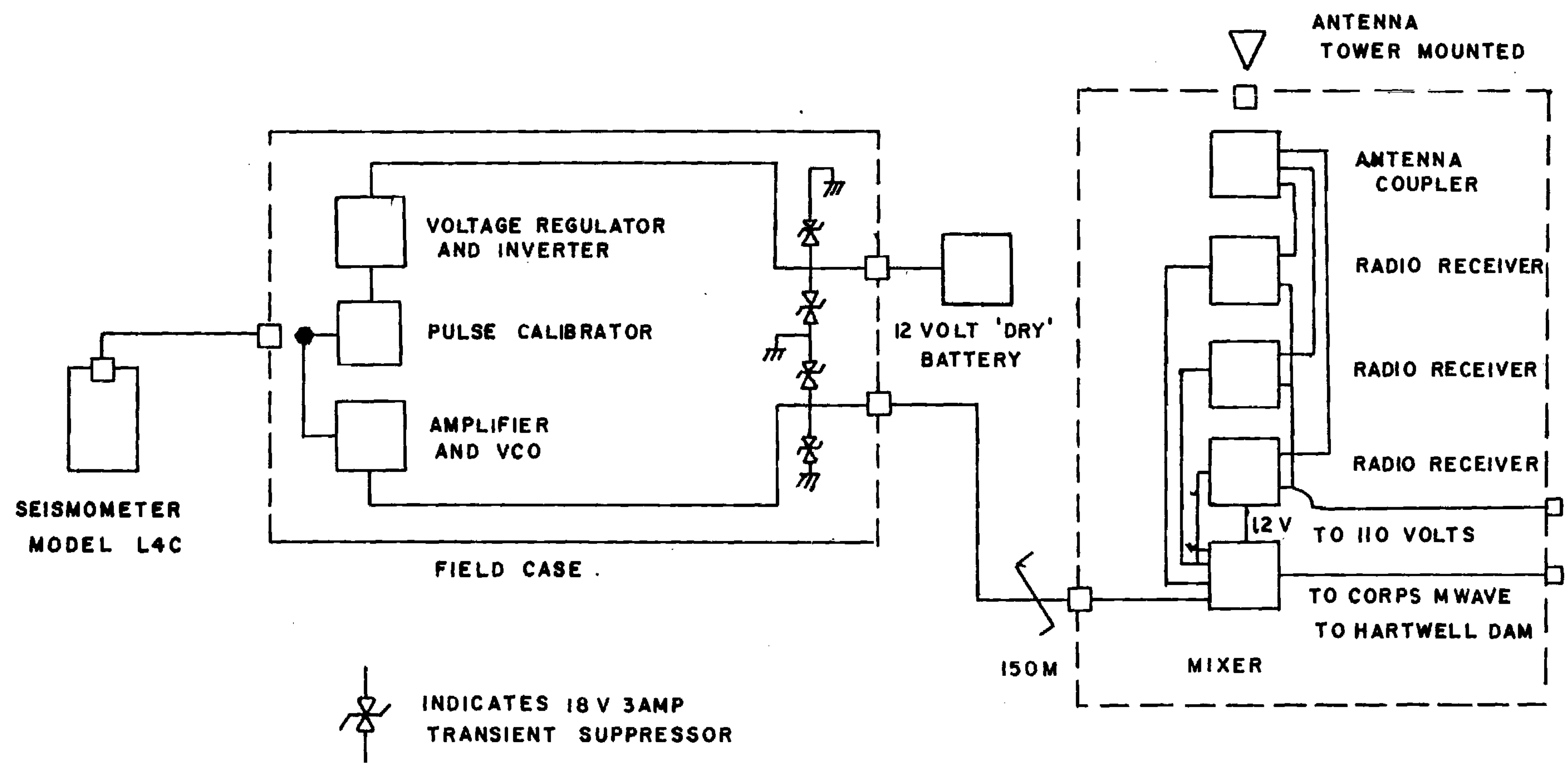


Figure 6. Field instrumentation for the Richard B. Russell Seismic Network. Stations CHF, and the relay site (RBR microwave tower).

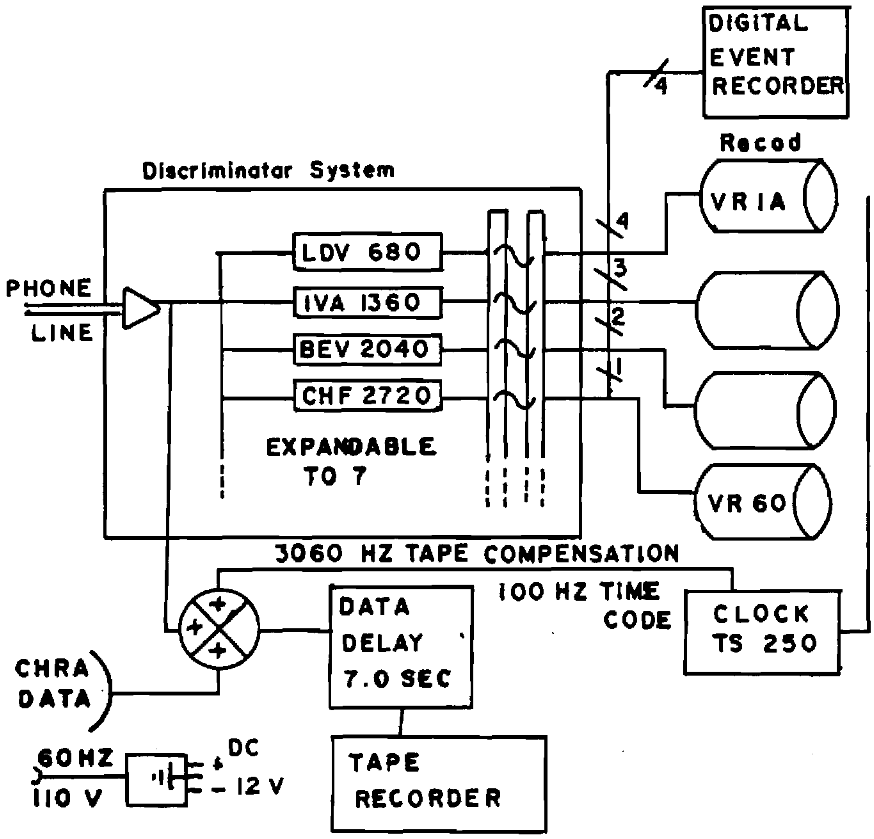
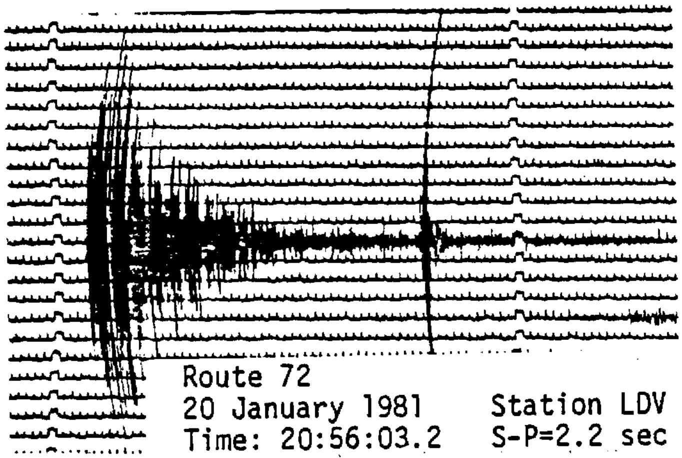
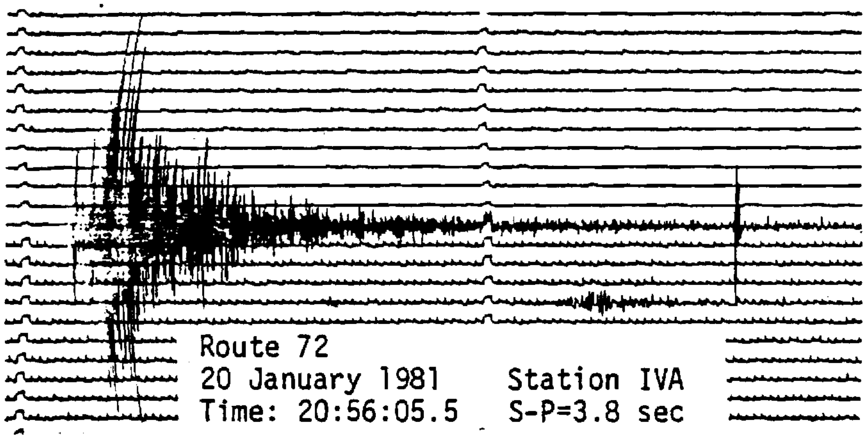


Figure 7. Design of the Richard B. Russell Lake Seismic Network instrumentation at Georgia Tech.


Route 72
20 January 1981
Time: 20:56:03.2
Station LDV
S-P=2.2 sec


Route 72
20 January 1981
Time: 20:56:05.5
Station IVA
S-P=3.8 sec

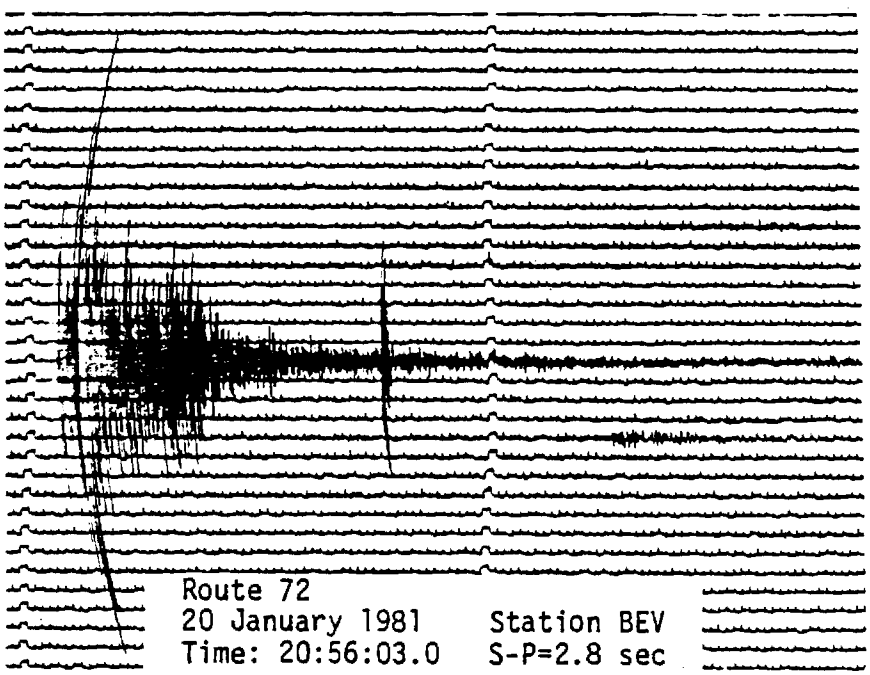

Route 72
20 January 1981
Time: 20:56:03.0
Station BEV
S-P=2.8 sec

Figure 8A.

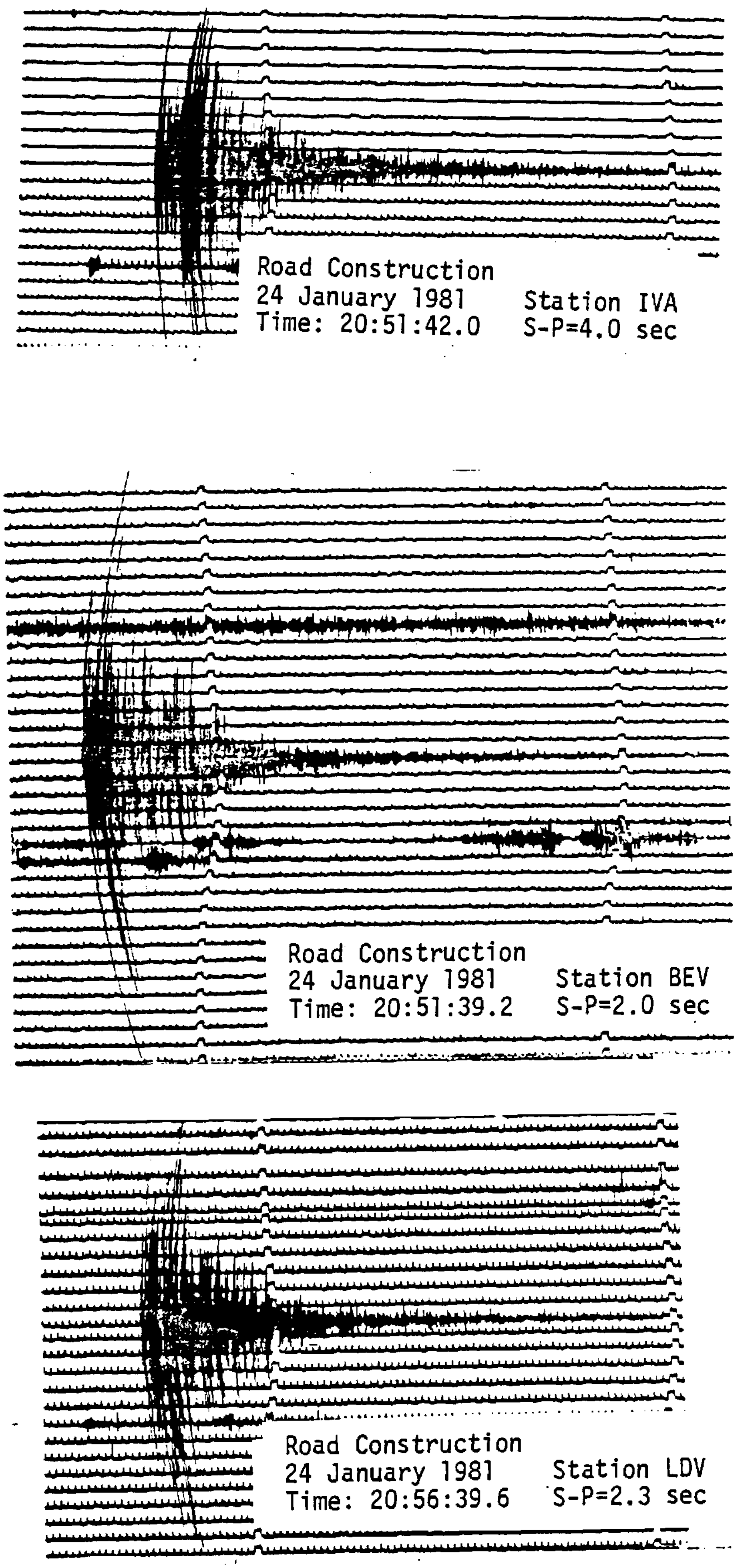
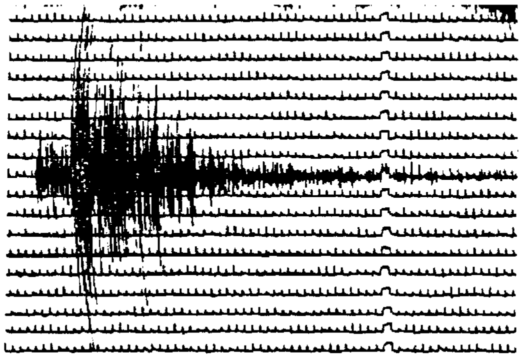
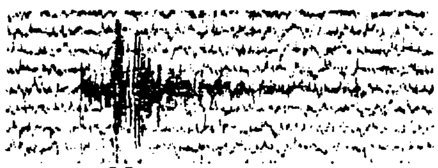

Road Construction
24 January 1981
Time: 20:51:42.0
Station IVA
S-P=4.0 sec
Road Construction
24 January 1981
Time: 20:51:39.2
Station BEV
S-P=2.0 sec
Road Construction
24 January 1981
Time: 20:56:39.6
Station LDV
S-P=2.3 sec

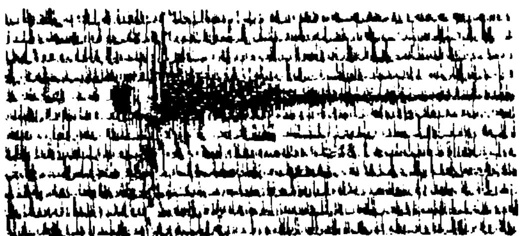
Figure 8B.



Hartwell Quarry, GA
01 June 1983 Station BEV
Time: 19:05:15 S-P=4.8

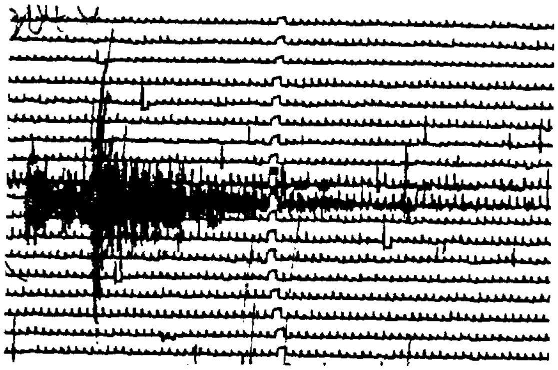


Hartwell
17 July 1981 Station LDV
Time: 16:15:56 S-P=4.0 sec

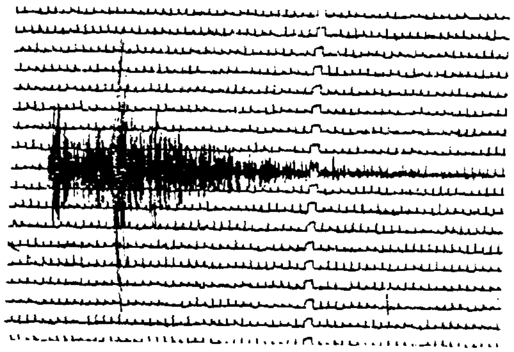


Hartwell
17 July 1981 Station IVA
Time: 16:15:54 S-P=3.2 sec

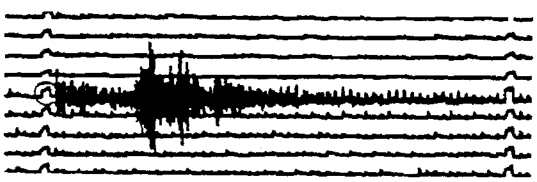
Figure 8C.



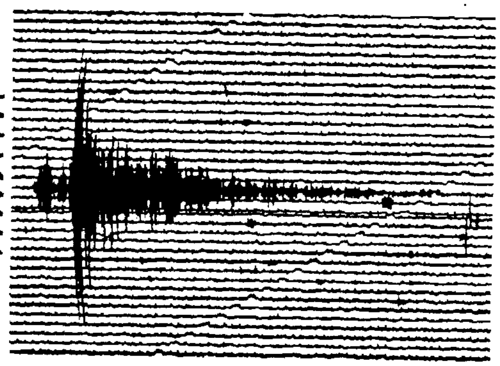
Thomson Quarry, GA
12 July 1983 Station LDV
Time: 20:46:28 S-P=9.2



Thomson Quarry, GA
13 June 1983 Station BEV
Time: 18:13:26 S-P=8.5

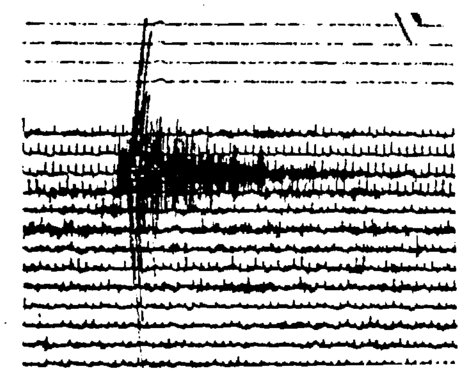


Thomson Quarry, GA
12 October 1983 Station IVA
Time: 17:28:02 S-P=10.5



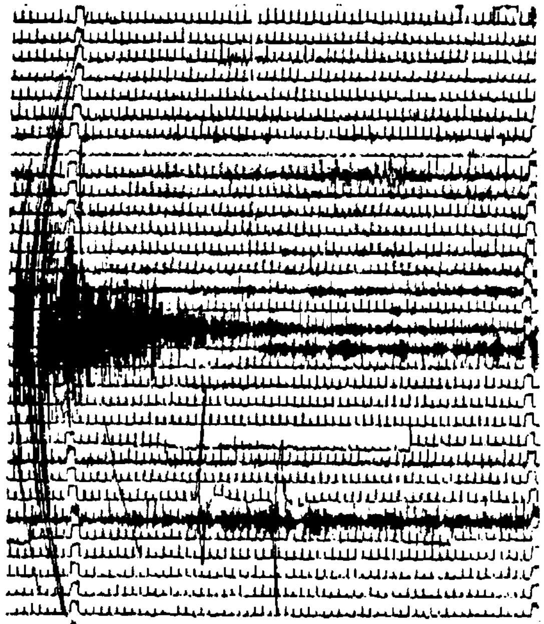
Thomson Quarry
17 March 1983 Station CH5
Time: 20:41:08 S-P=5.0

Figure 8D



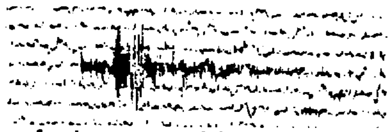
Richard B. Russell Dam
14 August 1981 Station LDV
Time: 18:58:13.5 S-P=1.4 sec

Figure 8E.

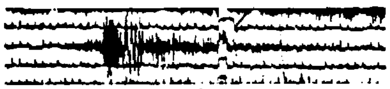


Calhoun Falls, SC
28 August 1981 Station CH6
Time: 18:58:12.5 S-P=2.0 sec

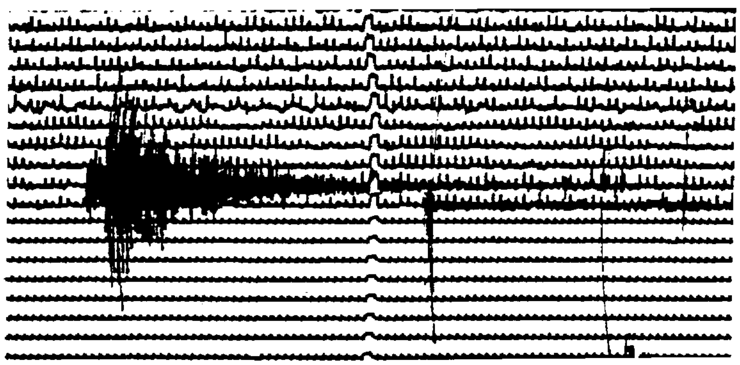
Figure 8F.



Anderson, SC
6 October 1981 Station LDV
Time: 16:14:39 S-P=4.0 sec

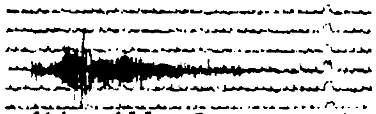


Anderson, SC
6 October 1981 Station BEV
Time: 16:14:40 S-P=4.8 sec

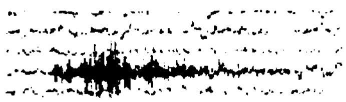


Anderson Quarry, SC
17 October 1983 Station IVA
Time: 20:48:23 S-P=3.0

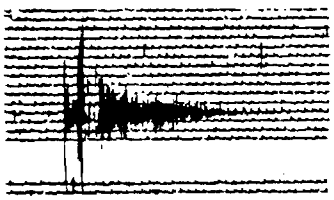
Figure 8G.



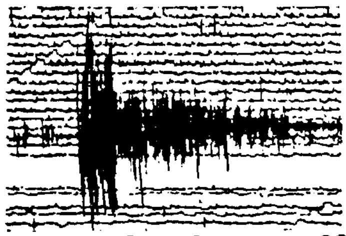
Abbeville Quarry, SC
9 October 1981 Station BEV
Time: 15:48:22 S-P=6.0 sec



Abbeville Quarry, SC
9 October 1981 Station LDV
Time: 15:48:23 S-P=5.0 sec

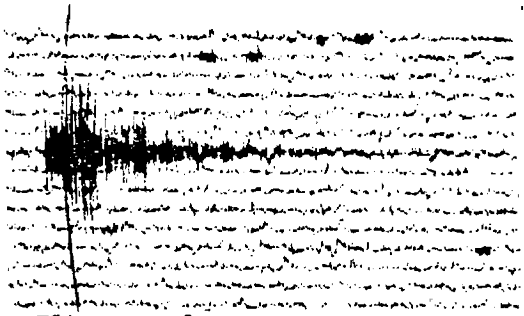


Abbeville Quarry, SC
9 October 1981 Station EP1
Time: 15:48:18.5 S-P=2.0 sec

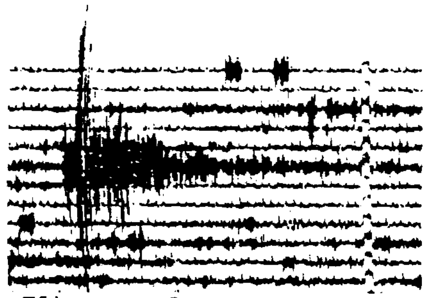


Abbeville Quarry, SC
9 October 1981 Station CH6
Time: 15:48:19.2 S-P=1.8 sec

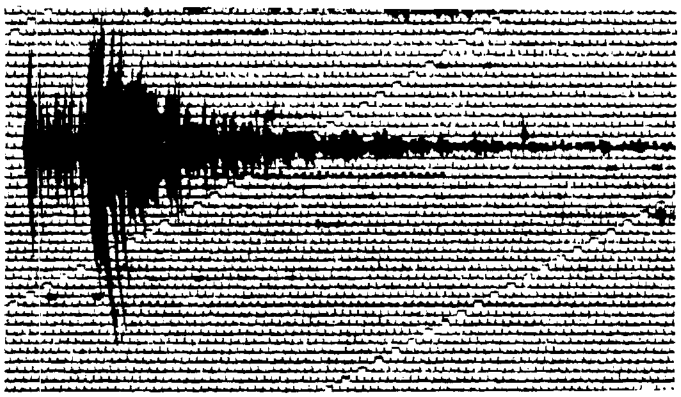
Figure 8H



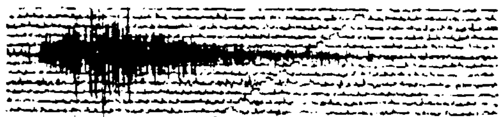
Elberton Quarry
9 October 1981 Station LDV
Time: 17:30:22 S-P=2.4 sec



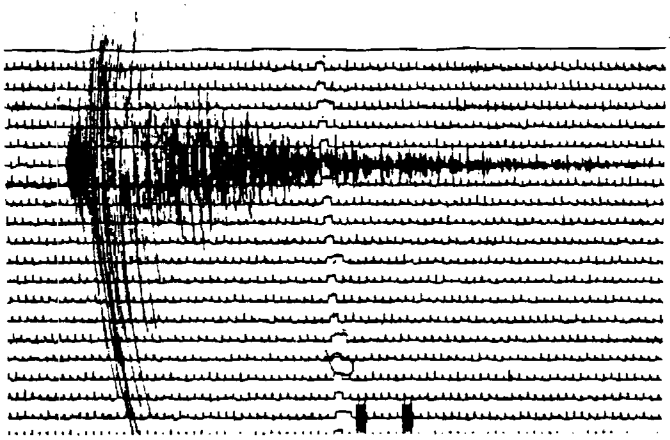
Elberton Quarry
9 October 1981 Station BEV
Time: 17:30:21 S-P=1.7 sec



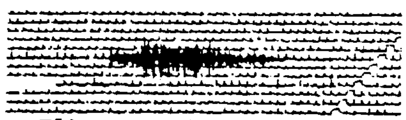
Elberton Quarry, GA
04 April 1983 Station CH5
Time: 20:03:25 S-P=8.2



Elberton Quarry
9 October 1981 Station CH6
Time: 17:30:25 S-P=6.0 sec

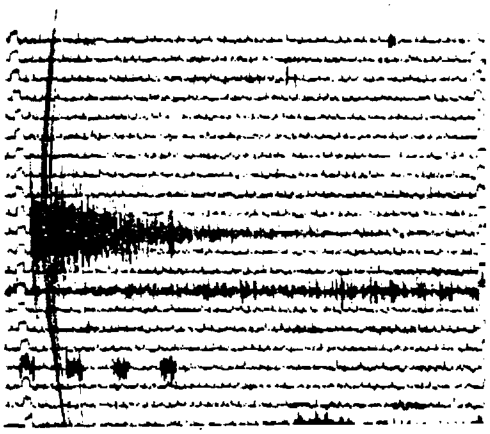


Elberton Quarry, GA
19 Feb. 1983 Station IVA
Time: 17:44:27 S-P=2,9

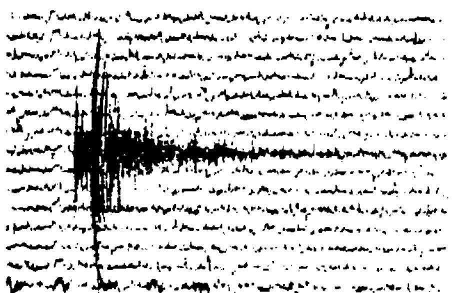


Elberton Quarry
9 October 1981 Station EP1
Time: 17:30:25 S-P=4.2 sec

Figure 8I.

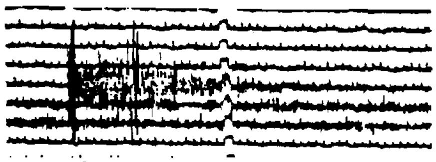


New blast site above Elberton
10 November 1981 Station BEV
Time: 18:27:02 S-P=1.9 sec

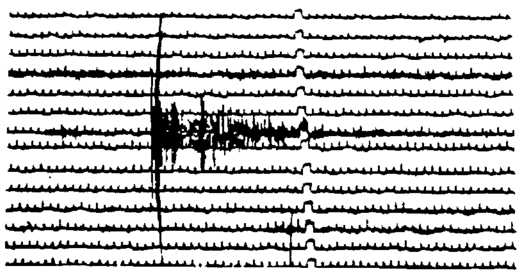


New blast site above Elberton
10 November 1981 Station LDV
Time: 18:27:03 S-P=2.4 sec

Figure 8J.



Heardmont
15 December 1981 Station BEV
Time: 17:06:39.9 S-P=0.6 sec



Heardmont
15 December 1981 Station LDV
Time: 17:06:39.4 S-P=0.8 sec

Figure 8K.

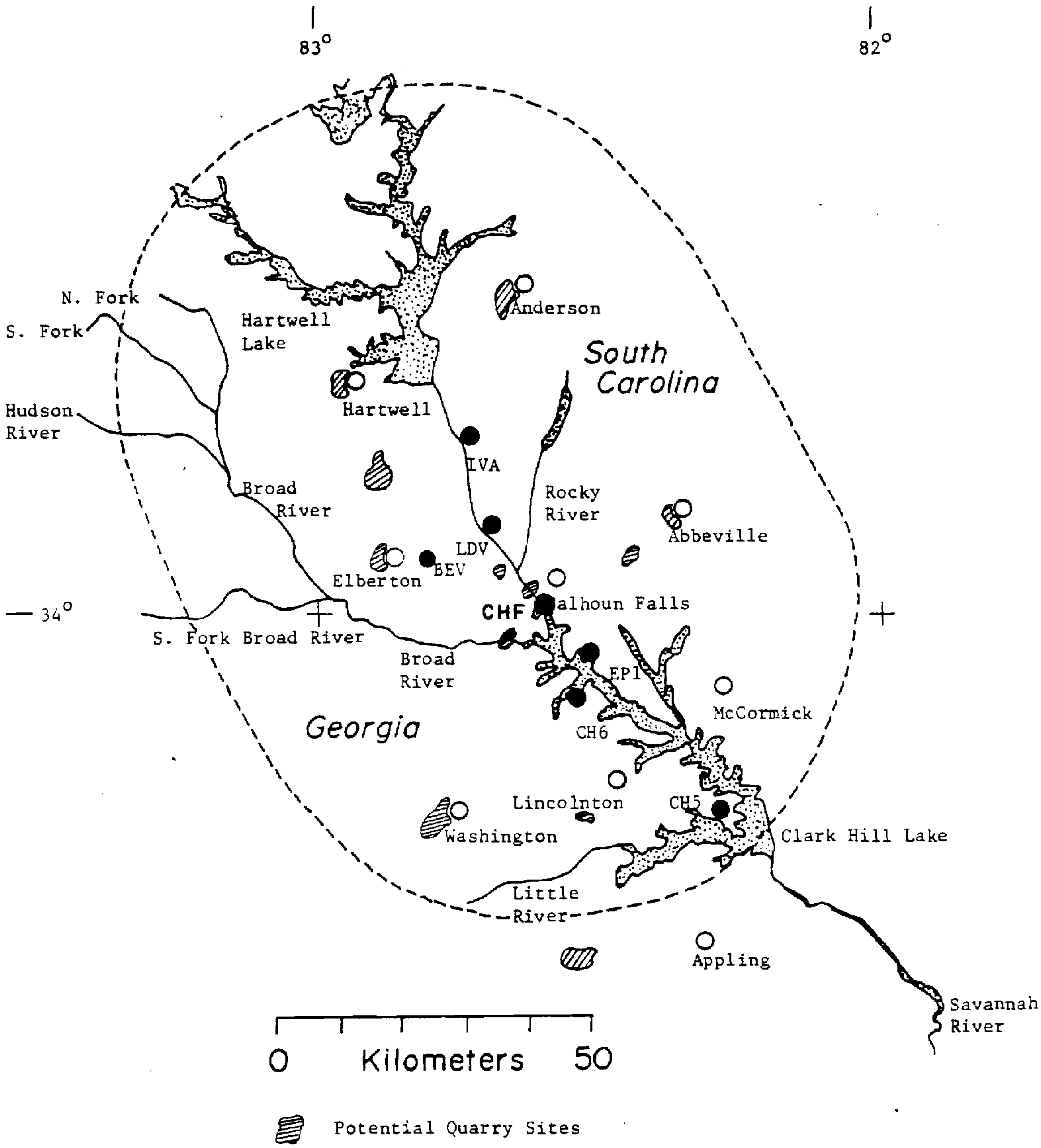


Figure 9. Area of investigation and locations of quarries active during the first period of operation of the Seismic Net.

Table 1. Station Operation Periods

Month	CHF	IVA	BEV	LDV	One Station Coverage	Two Station Coverage	Three Station Coverage	Four Station Coverage
January	0%	65%	21%	80%	94%	56%	16%	0%
February	70%	68%	59%	18%	77%	72%	54%	9%
March	74%	73%	0%	72%	75%	73%	70%	0%
April	83%	99%	24%	83%	100%	99%	82%	8%
May	57%	92%	90%	75%	93%	90%	79%	53%
June	12%	87%	85%	80%	89%	86%	78%	11%
July	0%	15%	85%	47%	87%	45%	14%	0%
August	27%	29%	83%	86%	88%	85%	29%	24%
September	97%	89%	89%	94%	97%	94%	93%	88%
October	16%	66%	79%	74%	84%	80%	58%	13%
November	0%	73%	94%	50%	100%	83%	31%	0%
December	45%	19%	97%	8%	99%	76%	6%	0%
Average Coverage over 12 Months	40%	65%	67%	64%	90%	78%	51%	17%

Explanation of Station Coverage

Station coverage is broken down as follows:

One Station Coverage - the percentage of time that at least one of the four stations is functioning normally.

Two Station Coverage - the percentage of time that at least two of the four stations are functioning normally.

Three Station Coverage - the percentage of time that at least three of the four stations are functioning normally.

Four Station Coverage - the percentage of time that all four stations are functioning normally.

REGIONAL SEISMICITY

During the course of the year, several regional seismic events were detected by the stations IVA, BEV, LDV, and CHF. This is a good indication that the above stations are indeed picking up seismic events of a nature other than blasts and that they are functioning properly. A catalog indicating the character and specifics of the regional events can be found on pages 33-38.

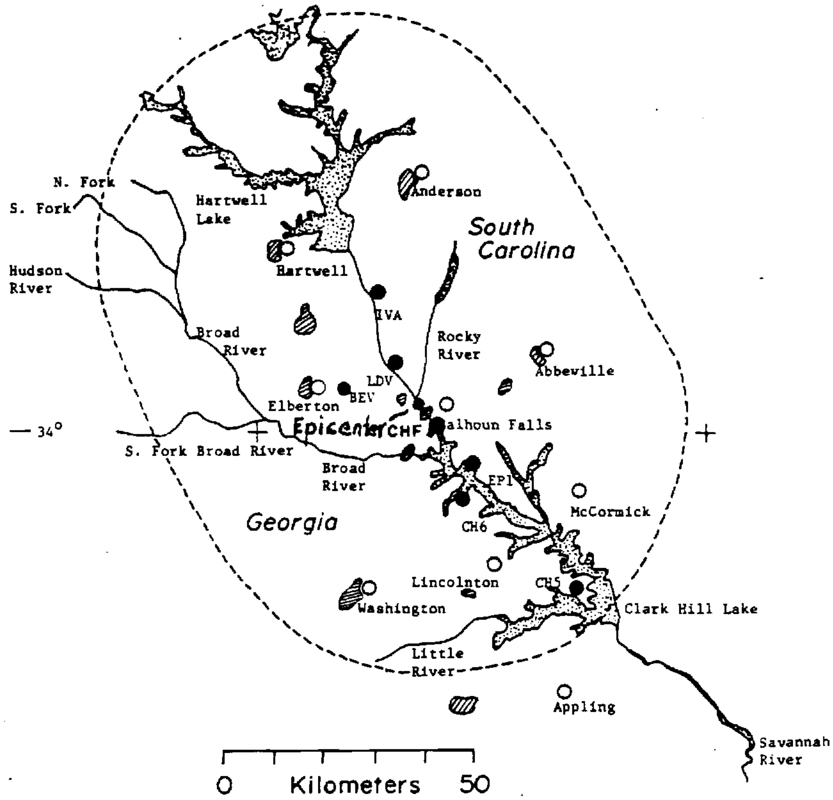
SUSPECTED INDUCED SEISMICITY

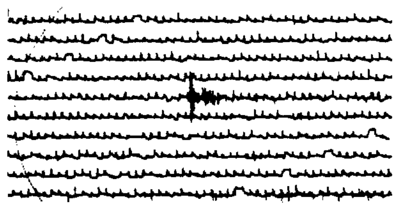
Two events of suspected natural origin have been detected in the defined area of the Richard B. Russell Seismic Network. These events were detected on 13 March 1984 and 22 October 1984. The epicenters are near Calhoun Falls and Paris Island, now submerged under the new reservoir (Figure 10). Even though the computer location places the epicenter of these two events 6 kilometers apart, we feel the source is the same. Because the close-in station, BEV, was not used in one of the location determinations, and because of the uncertainty resulting from the error in picking arrival times of small events, the difference in location can be considered within the range of uncertainty of location capability (Figures 11a and 11b).

The occurrence of these events seems to be isolated in time. We have identified no additional natural seismic activity in this area. Also, we were unable to identify an alternate explanation for these two events. The earthquake locations are not precise enough to associate them with any known fault in the area. However, upon inspection of a preliminary geological reconnaissance map of the RBR area, a granitic gneiss/mica schist is mapped in the same area as the epicenters (Figure 12). Granitic gneiss/mica schists of a similar type are believed to be associated with induced earthquakes near other reservoirs in Georgia and South Carolina. These reservoirs include the Monticello and Jocassee Reservoir, both in the South Carolina Piedmont geologic province. The possibility exists that this particular rock unit might be associated with the seismic events in the Richard B. Russell Reservoir area.

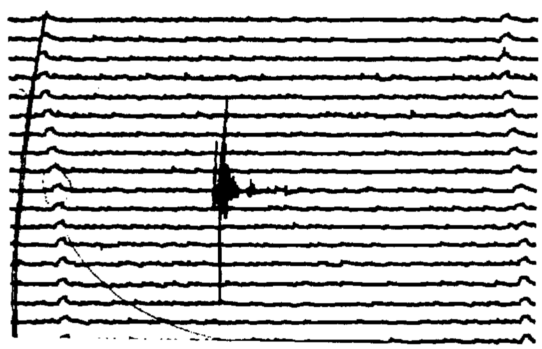
SEISMIC VELOCITY ANALYSIS

In 1984, a velocity study of the Richard B. Russell Reservoir area was completed. Industrial explosions recorded on the analog records were inspected for the arrival times of the different seismic phases. In addition, data collected from a digital event recorder were also analyzed, and the travel time for each phase was noted. Because the locations of the quarries were well known, source-to-receiver distances were easily calculated with precision. When enough data were analyzed, a time-versus-distance plot was constructed (Figure 13). Results from a least squares, best fit line indicate that the compressional wave (P-wave) velocity in the crystalline rock is 6.05 kilometers per second.

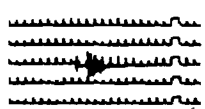




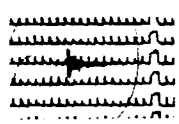
12 March 1984
Station IVA



12 March 1984
Station LDV



22 October 1984
Station BEV



22 October 1984
Station LDV

Figure 10. Epicenter and seismograms of suspected induced event.

```
THE EVENT OCCURED ON MAR 13, 1984
AT ORIGIN TIME  5:56:18.84 +/-     .221
RBR
MAGNITUDE: 0.0
THE WEIGHTS ARE
WX=  1.000  WY=  1.000  WZ=  0.000  WT=  1.000
IT WAS LOCATED AT
LATITUDE    34.0703  +/-   1.999 KM.  (34D, 4.22M)
LONGITUDE   82.6723  +/-   1.149 KM.  (82D,40.34M)
DEPTH         0.00   +/-   0.000 KM.
```

STATION	PHASE	HR	MIN	SEC	+OR-SEC	DIST	AZ	OBS-THE	THEOR
LDV	PG	5	56	20.50	.01	8.67	353.3	.087	21380.41
LDV	S	5	56	21.50	.01	8.68	353.3	-.068	21381.57
IVA	S	5	56	26.20	.10	23.40	343.1	-.004	21386.20
CH6	SC	5	56	25.20	.10	23.62	145.9	-.391	21385.59
CHF	S	5	56	22.00	.10	9.40	122.6	.205	21381.80

```
DIAGONAL ELEMENTS
    2.0589     1.0418      .2114

COVARIANCE MATRIX:

   79.503   -42.381    -7.725     0.000
  -42.381    26.248     4.405     0.000
   -7.725     4.405      .973     0.000
    0.000     0.000     0.000     0.000

ERROR ELLIPSE IS AS FOLLOWS:
MINOR AXIS LENGTH      =      .5406 KM.
MAJOR AXIS LENGTH      =     3.2636 KM.
AZIMUTH OF MAJOR AXIS  =    28.9295 DEG.
AREA OF ELLIPSE        =     5.5424 SQ.KM.

 MEAN RESIDUAL :     -.03414  STANDARD DEVIATION :      .22424
 NO DEPTH COMPUTATION
```

Figure 11a. Computer location of the March 13, 1984, suspected reservoir induced earthquake.

```
THE EVENT OCCURED ON OCT 22, 1984
AT ORIGIN TIME  7: 2:45.59 +/-     .030
RBR
MAGNITUDE: 0.0
THE WEIGHTS ARE
WX=  1.000  WY=  1.000  WZ=  0.000  WT=  1.000
IT WAS LOCATED AT
LATITUDE    34.0505  +/-     .315 KM.  (34D, 3.03M)
LONGITUDE   82.6146  +/-     .216 KM.  (82D,36.87M)
DEPTH         0.00   +/-    0.000 KM.

 STATION PHASE    HR MIN  SEC +OR-SEC  DIST    AZ        OBS-THE  THEOR.
   LDV    PC      7   2 47.60    .10   12.52  329.6     -.085  25367.68
   LDV    SC      7   2 49.20    .10   12.52  329.6     -.016  25369.22
   BEV    PC      7   2 47.50    .10   11.78  291.4     -.064  25367.56
   BEV    SC      7   2 49.05    .10   11.78  291.4      .043  25369.01
   CH6    PC      7   2 48.75    .10   19.09  155.5     -.004  25368.75
   CH6    SC      7   2 51.10    .10   19.09  155.5      .034  25371.07
   IVA    SC      7   2 53.50    .10   27.40  333.8      .092  25373.41
 DIAGONAL ELEMENTS
     1.6076     1.1025      .1509

COVARIANCE MATRIX:

    25.844    -14.066      1.352      0.000
   -14.066     12.155      -.483      0.000
     1.352      -.483       .228      0.000
     0.000      0.000      0.000      0.000

ERROR ELLIPSE IS AS FOLLOWS:
MINOR AXIS LENGTH      =       .1392 KM.
MAJOR AXIS LENGTH      =       .4473 KM.
AZIMUTH OF MAJOR AXIS  =     32.0262 DEG.
AREA OF ELLIPSE        =       .1956 SQ.KM.

 MEAN RESIDUAL :      .00000  STANDARD DEVIATION :      .06204
 NO DEPTH COMPUTATION
```

Figure 11b. Computer location of the October 22, 1984, suspected reservoir induced earthquake.

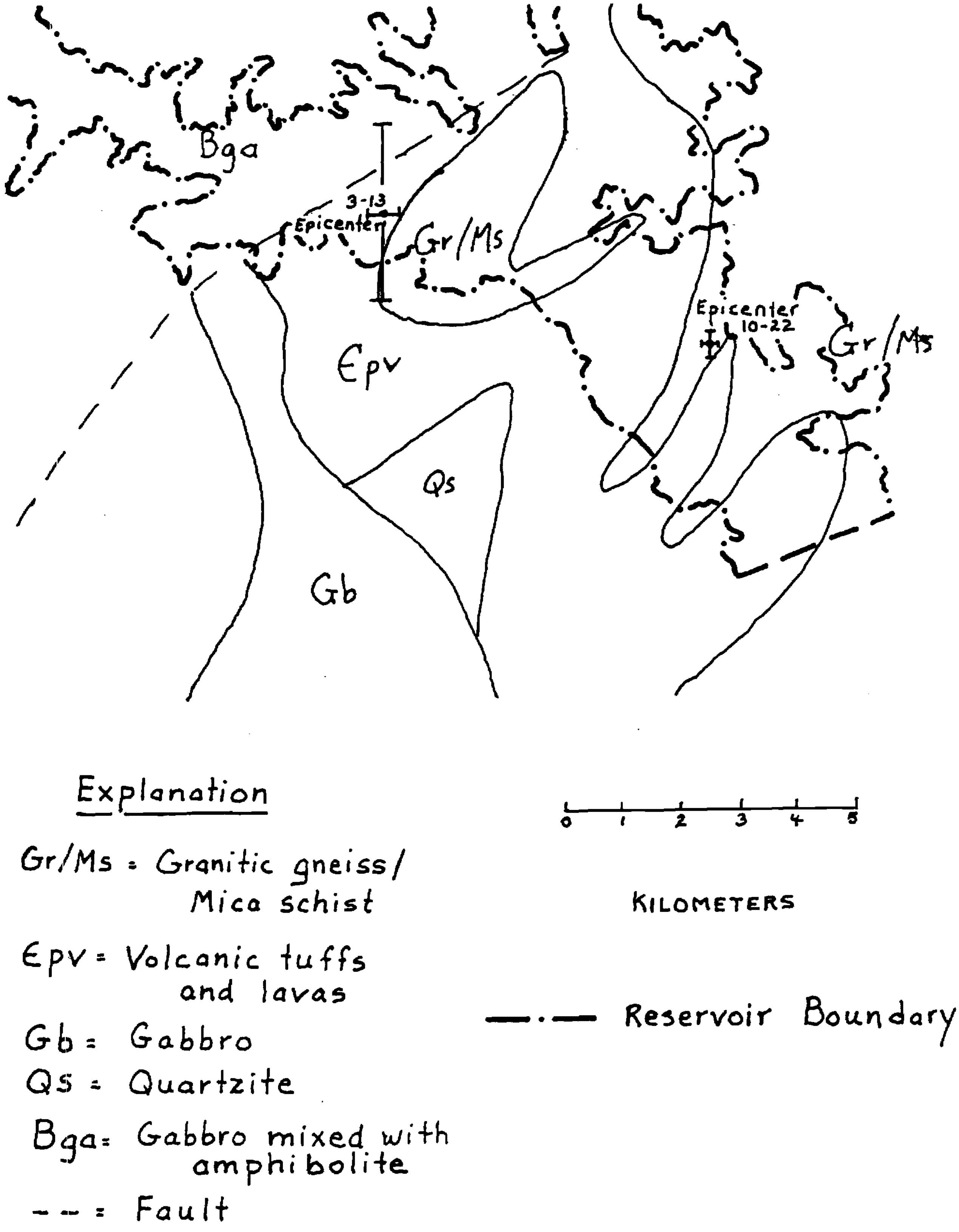


Figure 12. Detailed geology of the Richard B. Russell Reservoir area. Earthquake epicenters are also included.

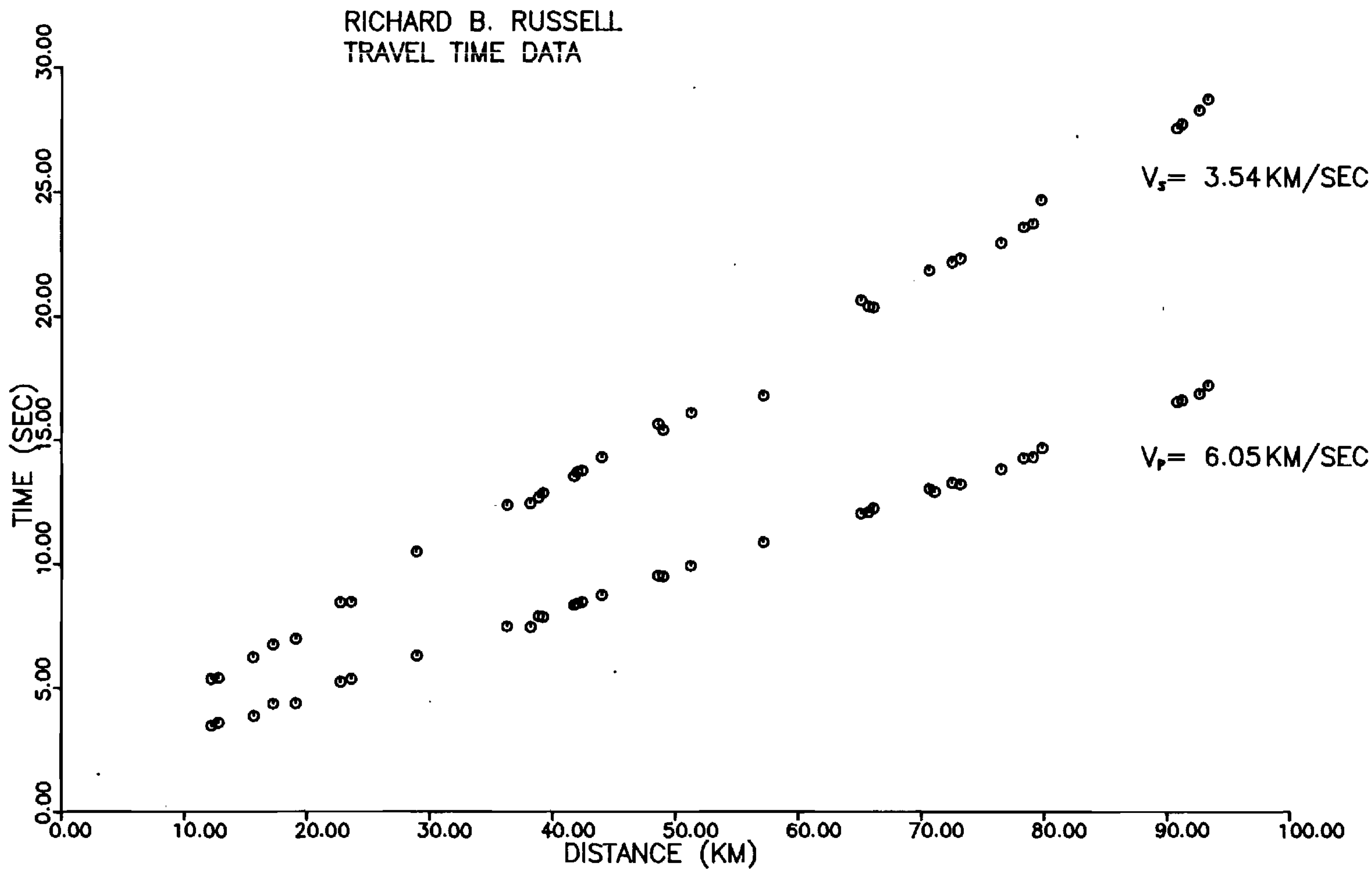


Figure 13. Richard B. Russell travel time curve.

Additionally, a least squares fit of the shear wave (S-wave) data indicates a shear wave velocity of 3.30 kilometers per second (Figure 14). There is no appreciable scatter in the travel time data.

Results of this study compare favorably with similar studies of the same region. In a study along strike in the same region, A. E. Kean and L. T. Long (1979) also determined the P-wave velocity to be 6.05 kilometers per second. Hence, the data indicate that the crust is isotropic. David Dunbar (1977) completed a similar study of the Clark Hill Reservoir Area. He proposed an increase of seismic velocity with depth, with velocities approaching 6.3 kilometers per second. Nevertheless, his results are consistent with those previously mentioned, since the 6.3 kilometers per second was found in a metadocite, and he obtained lower velocities in nearby granites.

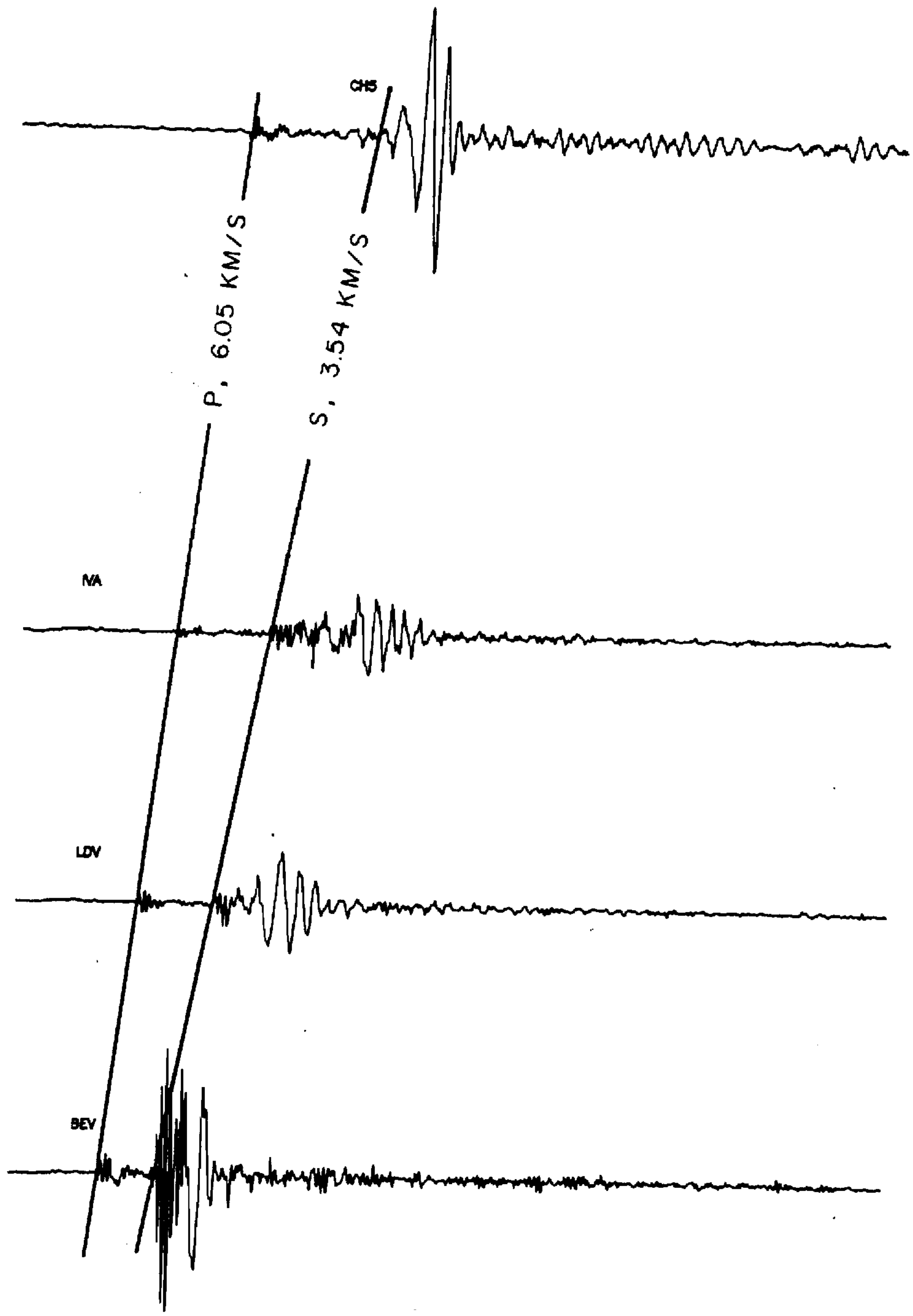
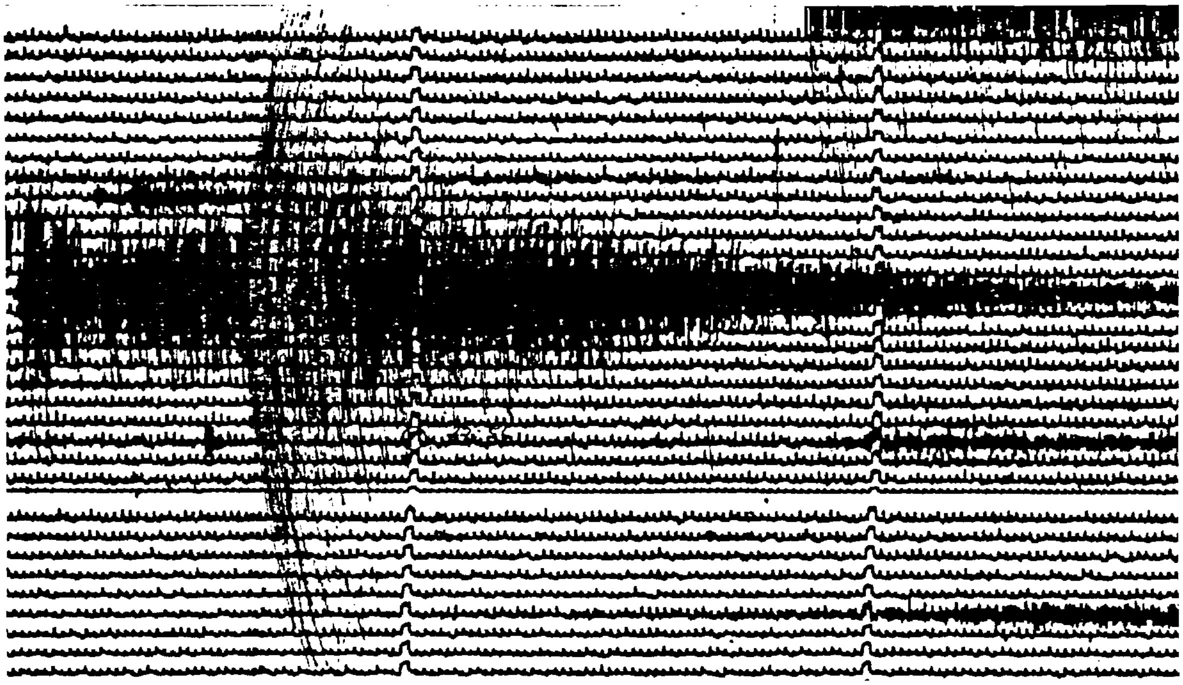
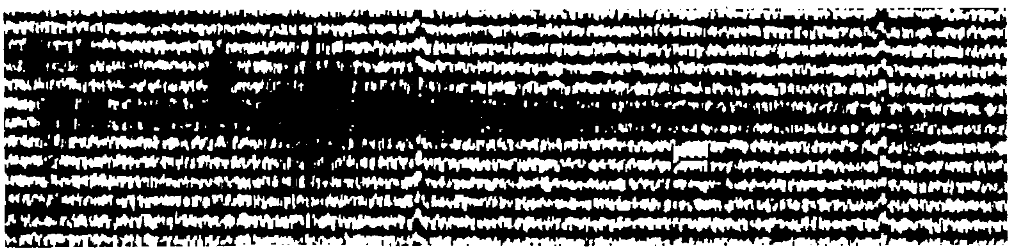


Figure 14. Digital representation of quarry blasts. Data from Richard B. Russell travel time study.



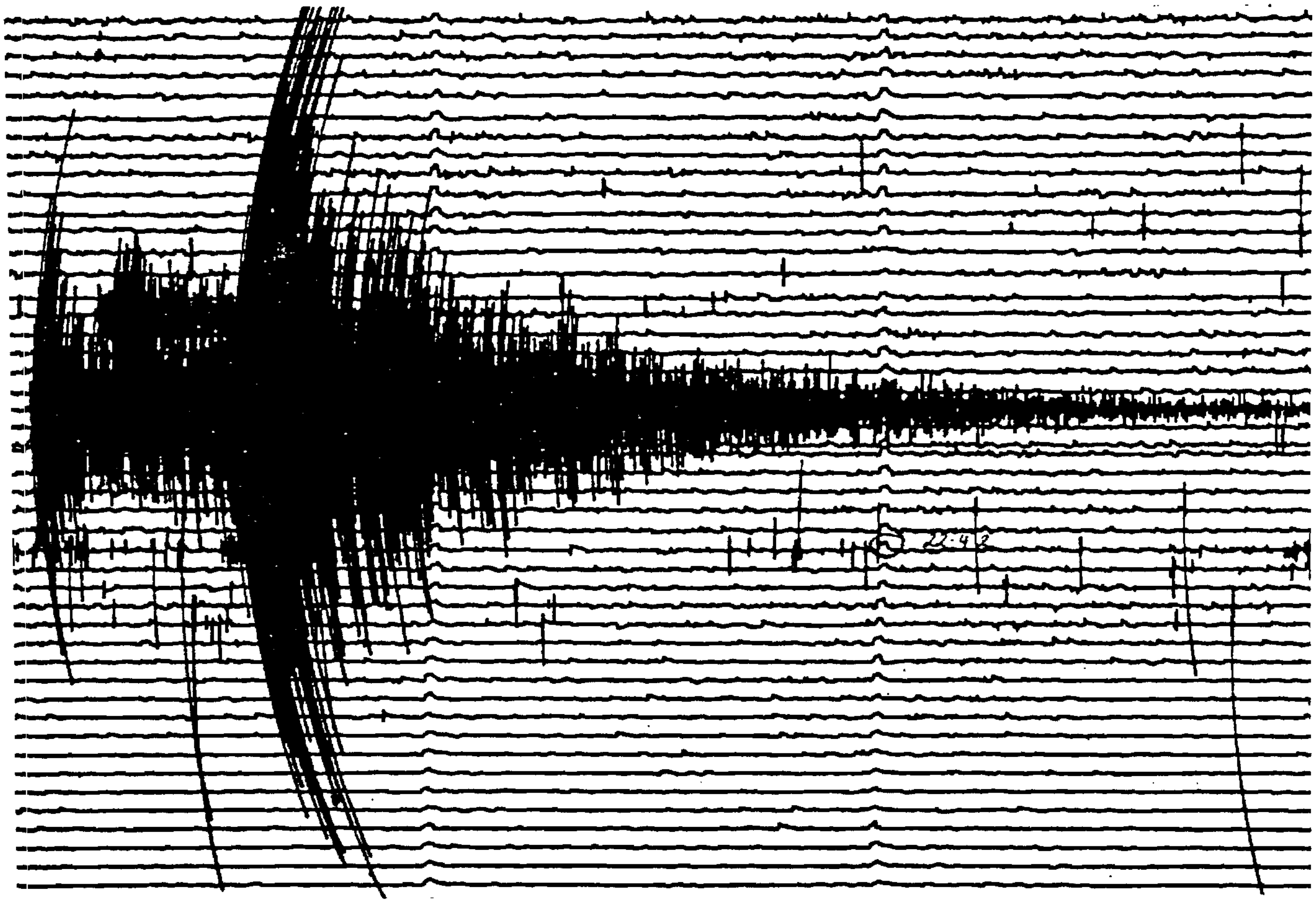
14 February 1984
Location: Knoxville, TN
Origin Time: 20:54:29.3

Station:	PLG	20:55:09.2
BEV	SLG	20:55:37.8



Knoxville, TN

Station	PLG	20:55:11.2
CHF	SLG	20:55:40.0

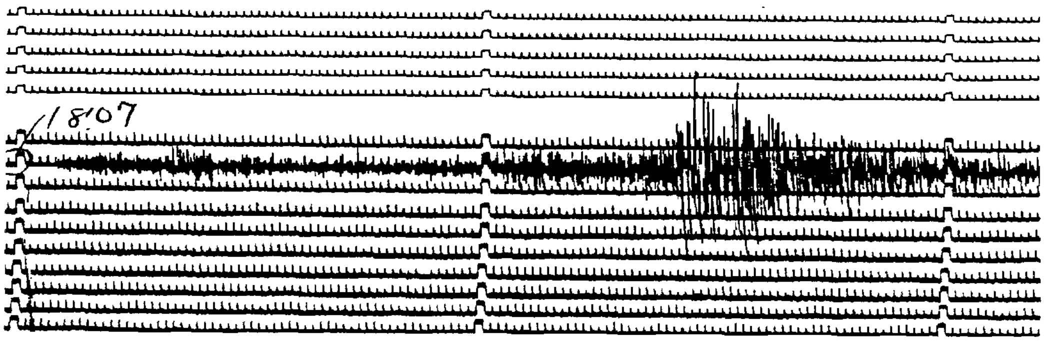


Knoxville, TN

Station PLG 20:55:06.1
IVA SLG 20:55:33.2

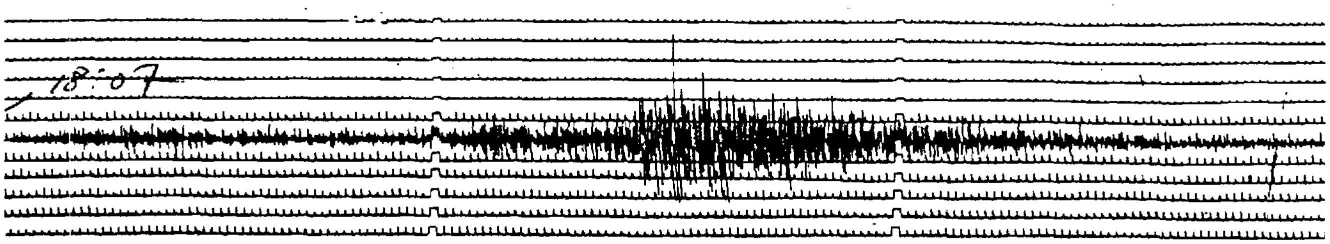
14 February 1984
Location: Arkansas

Station	PN	22:58:50.7
BEV	PLG	22:59:14.0



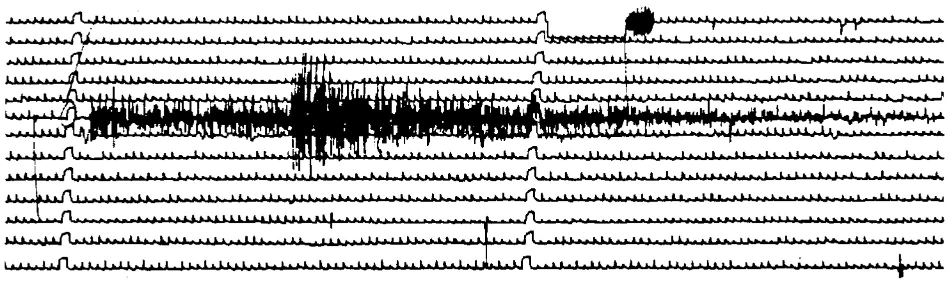
17 August 1984
Location: Virginia

Station PLG 18:07:05.1
LDV SLG 18:08:27.9



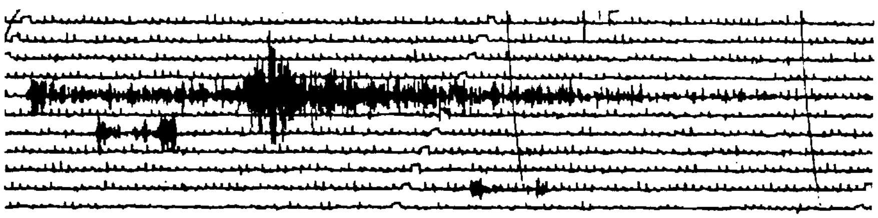
Virginia

Station PLG 18:07:05.5
BEV SLG 18:08:31.6



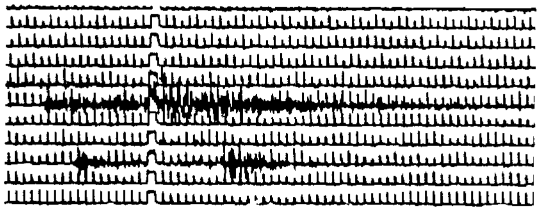
30 August 1984
Location: Greenback, TN
Origin Time: 16:26:26.34

Station	PLG	16:27:02.8
LDV	SLG	16:27:29.0



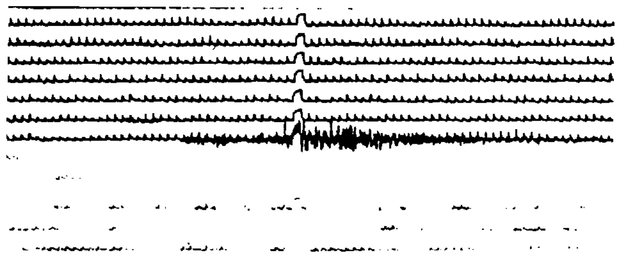
Greenback, TN

Station	PLG	16:27:05.7
CHF	SLG	16:27:33.5



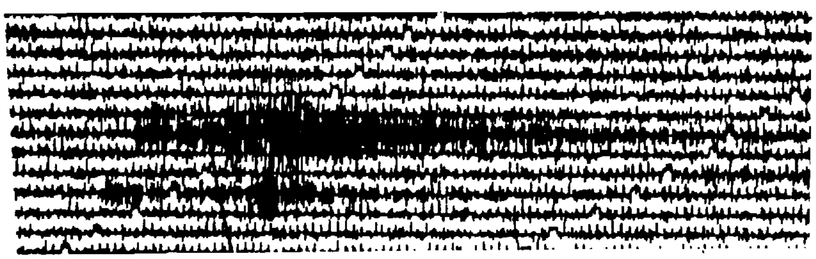
21 September 1984
Location: Brevard, NC
Origin Time: 20:46:22.48

Station PLG 20:46:46.5
BEV



Brevard, NC

Station PLG 20:46:45.4
LDV



Brevard, NC

Station PLG 20:46:43.6
IVA

Appendix I

Equipment assignments for IVA

Amplifier	419	VCO	Frequency	1360
Pulse Calibrator	164		Gain	66dB
Geophone	766		Filter low cut	0.2 Hz
Recorder	390		Filter high cut	25 Hz

The location of the telephone pole is indicated in the map. It is numbered E-1-37.

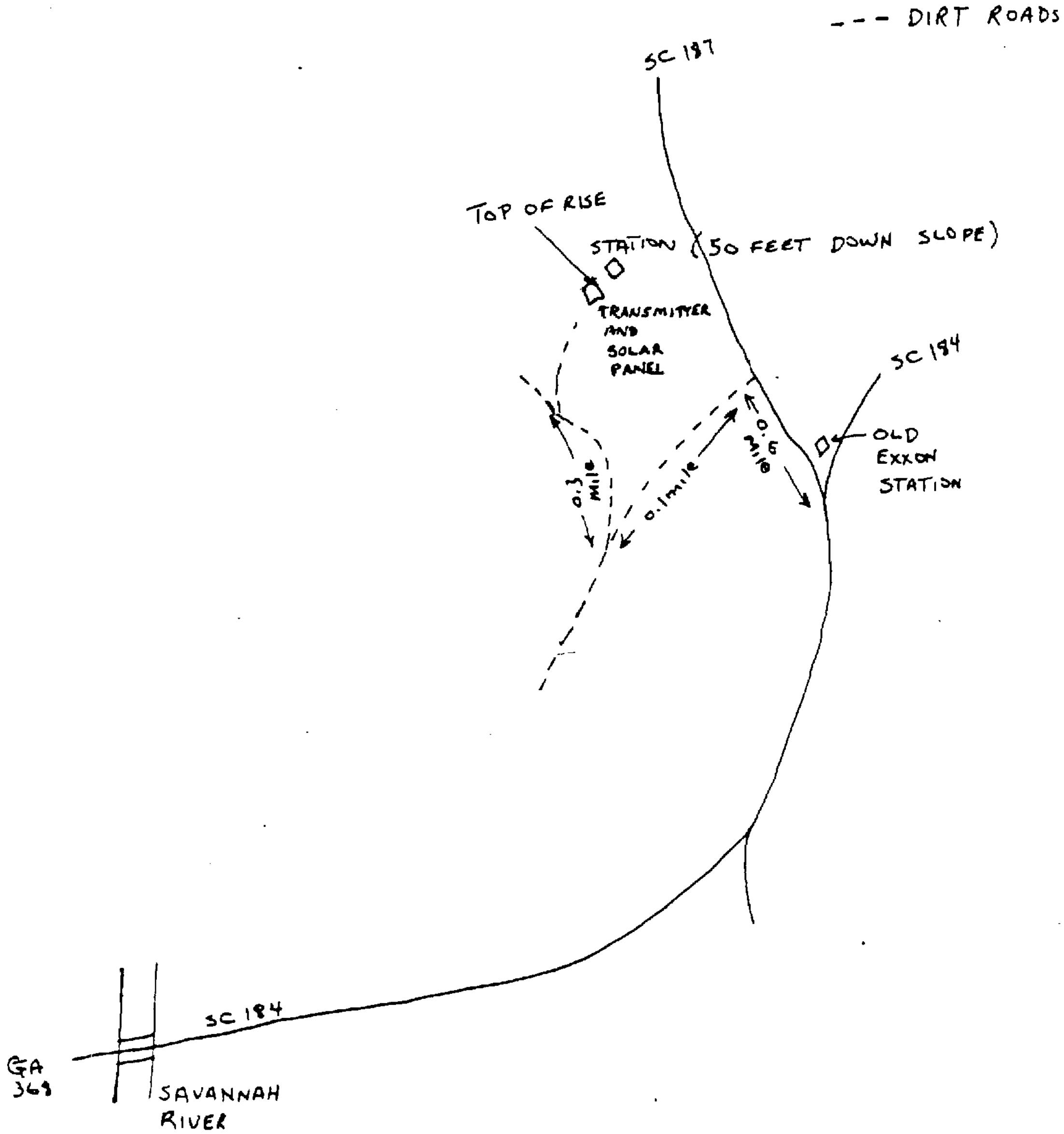
Vault Location:

Latitude	34.2721°N
Longitude	82.7460°W
Elevation	0.1676 km

The property is owned by the U. S. Army Corps of Engineers.

Directions to IVA:

From downtown Elberton take N. Oliver Road toward South Carolina. This road intersects with Georgia 368. There is an old gas station at the intersection. Take a right here. The road crosses the Savannah River and becomes S.C. 184. 184 forks into 184 and 187. Take the road to the left (187) and continue for 0.6 mile. A dirt road runs to the left here. Take it and turn right at the next dirt road. This road forks. Take the right fork. This will go to the edge of a hill. A worn path down on the right runs into the cable which can be followed down the hill to the station.



Directions to IVA (Continued)

Appendix I (Continued)

Equipment assignments for LDV

Amplifier	348	VCO Frequency	680
Pulse Calibrator	165	Gain	66dB
Geophone	768	Filter low cut	0.2 Hz
Recorder	386	Filter high cut	25 Hz

The location of the telephone pole is indicated in the map.

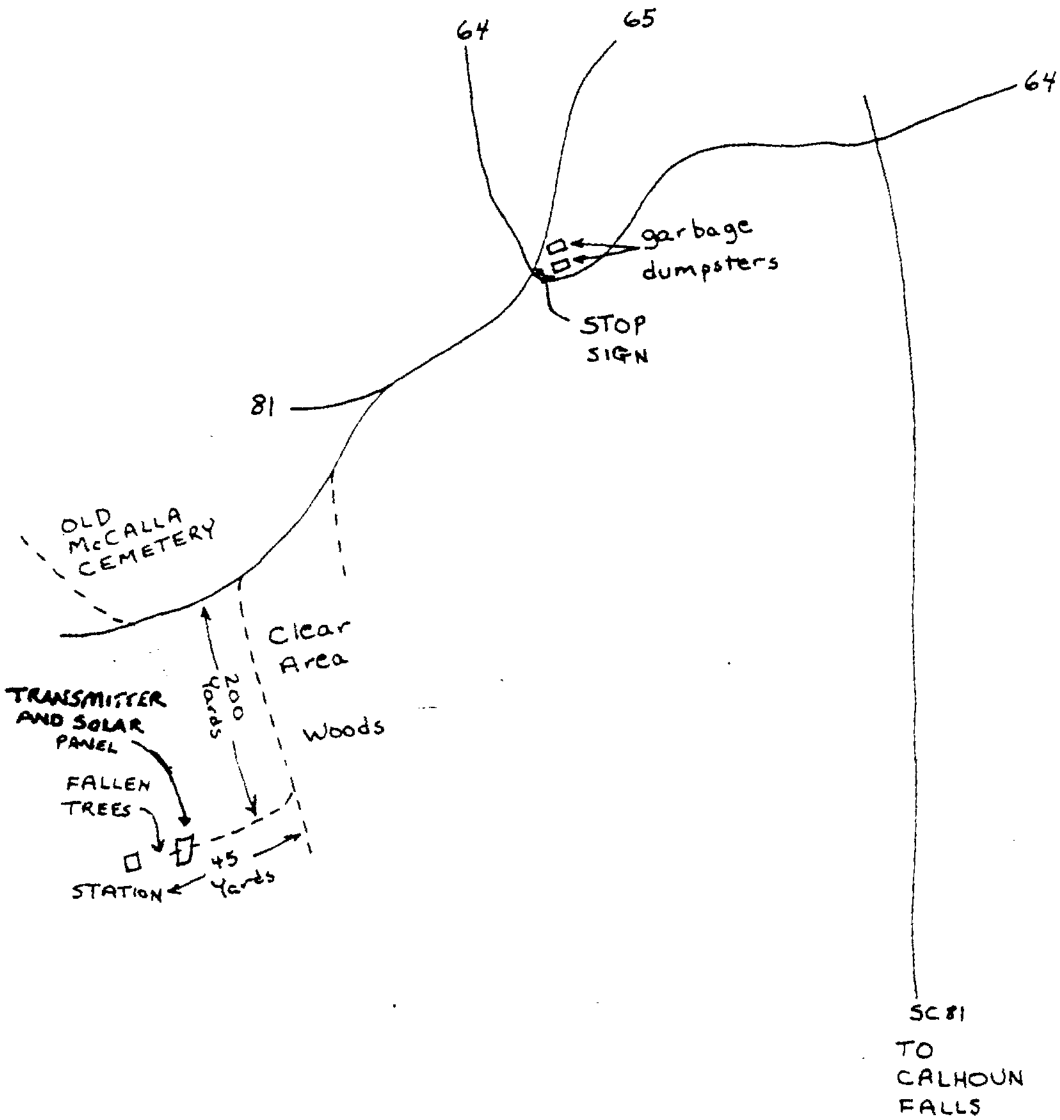
Vault Location:

Latitude	34.148°N
Longitude	82.6833°W
Elevation	0.1615 km

The property is owned by the U. S. Army Corps of Engineers.

Directions to LDV:

From Calhoun Falls take S.C. 81 north until it intersects with S.C. 64. Turn left onto 64 and cross the river (a future lake) and proceed to the stop sign. At the intersection turn left onto S.C. 65. Stay on 65 passing a fork to the right until the road forks into a dirt road to the left and a paved road to the right. This road runs through an open area of tall hardwood trees. Take the dirt road to the left that passes through these woods. Up this road about 200 yards another road which may be slightly overgrown runs to the right. Stop here, and follow the road through the woods on foot. The station is behind some fallen trees at the end of the road.



Directions to LDV (Continued)

Appendix I (Continued)

Equipment assignments for BEV

Amplifier	306	VCO Frequency	240
Pulse Calibrator	163	Gain	66dB
Geophone	767	Filter low cut	0.2 Hz
Recorder	391	Filter high cut	25 Hz

Location of the telephone pole:

Proceed north on Georgia Highway 245 from Georgia 72. The cable is tied to a pole as indicated on the site map. The pole is numbered No. 8P and is the third or fourth pole from the dumpster.

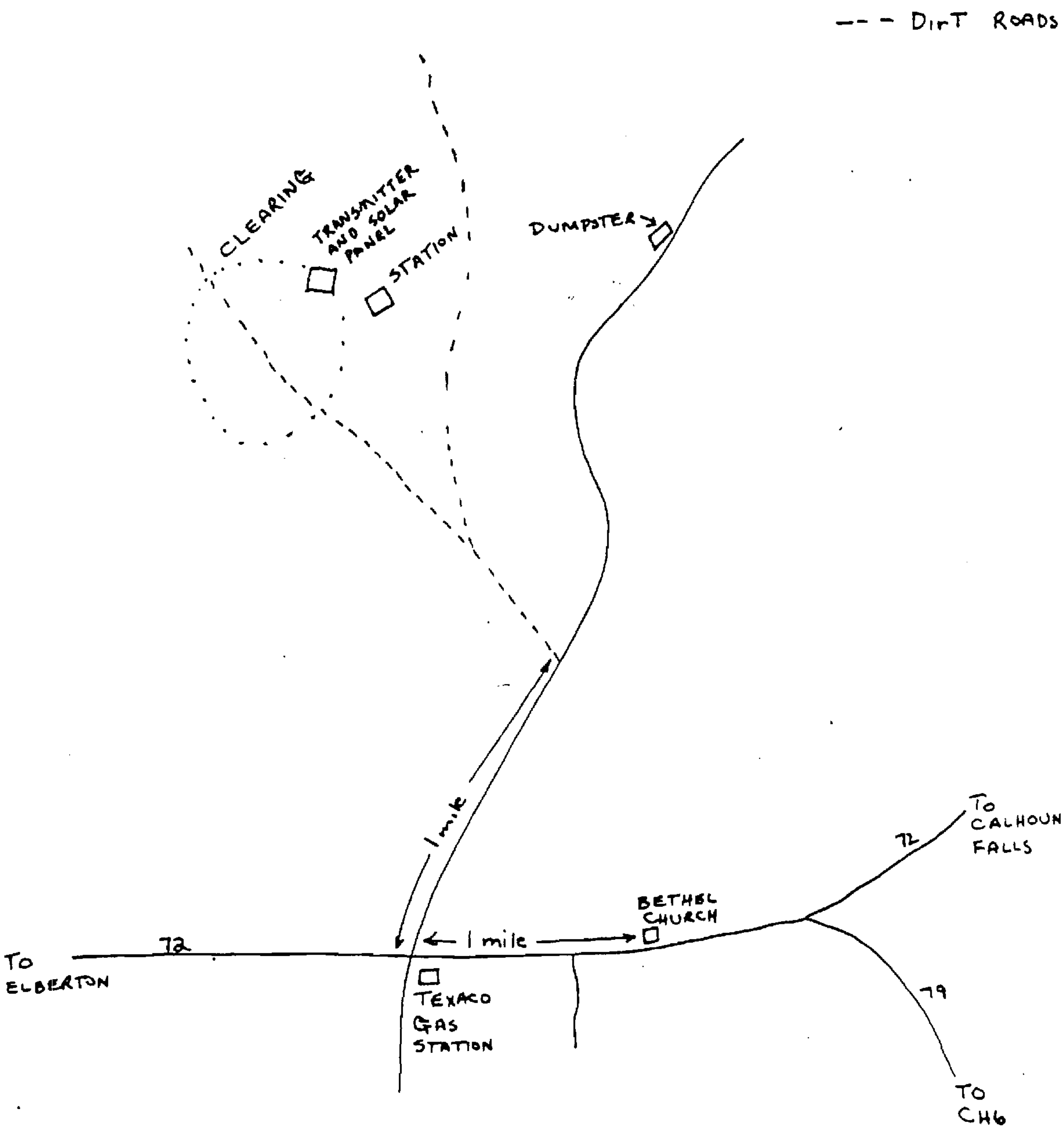
Vault Location:

Latitude	34.0893°N
Longitude	82.7334°W
Elevation	0.1584 km

The property is owned by the U. S. Army Corps of Engineers.

Directions to BEV:

From Elberton take Highway 72 westward through Middleton. There will be a Texaco station and a mini-market on the right. Make a left turn at the Texaco station. Take this road for about 0.95 miles. Take the dirt road here which forks to the left. This road will in turn fork to the right and left. Take the left fork. This road will run through a clearing about 100 yards in diameter. The station is on the right side about 50 feet from the edge of the open area.



Directions to BEV (Continued)

Appendix I (Continued)

Equipment assignments for CHF

Amplifier	Tech Built	VCO	Frequency	2720
Pulse Calibrator	Tech Built		Gain	72dB
Geophone	2936		Filter low cut	0.1 Hz
Recorder	5664		Filter high cut	30 Hz

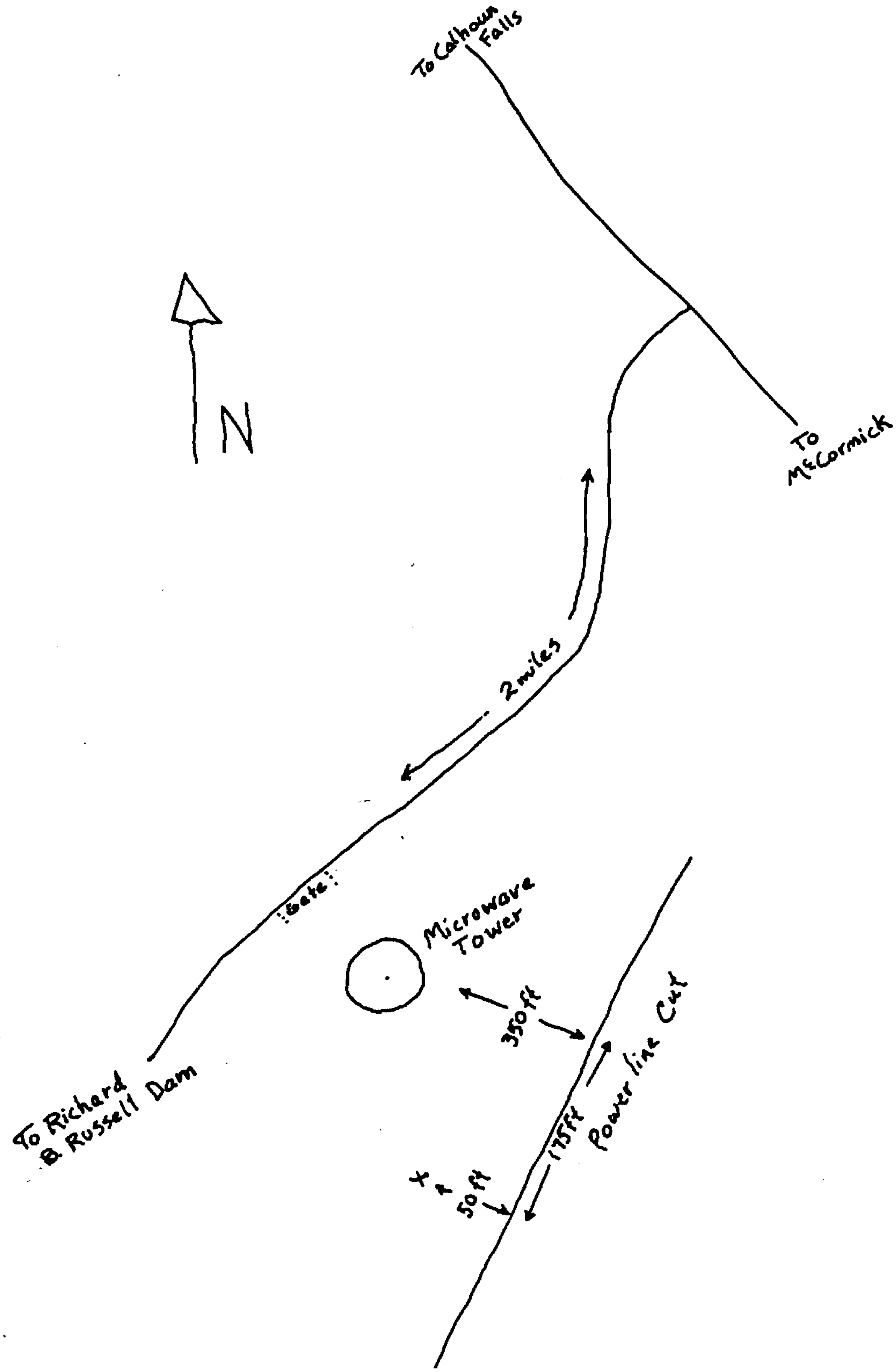
Vault Location:

Latitude	34.0247
Longitude	82.5867
Elevation	0.1520

The property is owned by the U.S. Army Corps of Engineers.

Directions to CHF:

From Elberton take Highway 72 westward to Calhoun Falls. At Calhoun Falls, turn right on Highway 81. Proceed on Highway 81 for about 2.6 miles. There will be a road on your right, which is the road to the dam. Take a right on this road. Travel down this road for about 2 miles. A very tall microwave tower should be on your left. Unlock the gate and park in front of the tower. Walk through the clearing of tress and then down the power line cut about 40 yards. The station is on your right side about 50 feet from the edge of the trees.



Directions to CHF (Continued)

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Kean, A. E., and L. T. Long (1980). A seismic refraction crustal study of the southeastern United States, Earthquake Notes, Vol. 51, No. 4, pp. 3-13.